Army Research Laboratory

Scalability of Robotic Controllers: An Evaluation of Controller Options

by Rodger A. Pettitt, Elizabeth S. Redden, and Christian B. Carstens

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14. ABSTRACT
This study, conducted at Fort Benning, Georgia, was an operational investigation of tele-operation control performance with the use of three different robotic control devices. Twelve Soldiers from the Officers' Candidate School and three Soldiers from Headquarters Company, 1st Battalion, 11th Infantry Regiment served as participants. Before any training, Soldiers provided an initial evaluation of the intuitiveness of controller features. After training in the operation of the IRobot PackBot Robot system, each Soldier completed a driving course using three different controller types. Controller A was the largest of the three controllers and each control manipulation had a single function. Both controller A and controller B had a similar number of single-function controls; however, controller B's controls were laid in a different configuration and were smaller than controller A's. Controller C had the fewest controls and the controls were multi-functional. Soldiers were tasked to drive the robot and to perform operations such as surveillance using the robotic arm. We measured workload for each controller was measured by having the Soldiers complete the NASA (National Aeronautics and Space Administration) Task Load Index survey after they used each controller type. Controller type and usability were evaluated, based on objective performance data, data collector observations, and Soldier questionnaires. The multifunctional controller was reported to be more difficult to learn and use than the controller with reduced control sizes because switching between functions was time consuming and confusing. This difficulty increased perceived workload. Soldiers also found that several robotic control functions (e.g., raising the control arm while turning the sensor head) could not be performed simultaneously with the multifunction controller. This necessitated sequential operation which was time consuming and difficult. Findings indicate that reducing the size of the individual controls shows promise as a valid approach for reducing overall controller size.

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control scalability; control size; dismounted Soldiers; robotic control; tele-operation

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1. Introduction

1.1 Statement of the Problem

Several streams of research are under way to delineate the degree and manner in which robotic controllers and displays can be scaled to the needs of Army Soldiers (Barnes, Knapp, Tillman, Walters, & Velicki, 2000; Barnes, Everett, & Rudakevych, 2005; Chen, Haas, & Barnes, 2007; Chen, Haas, Pillalamarri, & Jacobson, 2006; Renfro, Merlo, Duley, Gilson, & Hancock, 2007; Stafford, Jingjing, Merlo, & Hancock, 2007; Stafford, Hancock, Graham, & Merlo, 2007). This experiment is the second in a series of experiments designed to investigate current and future options for scaling robotic controls and displays specifically for use by dismounted Soldiers. The term "scalability" encompasses the various ways in which devices can be made more operationally effective, not only in terms of size and weight but also in terms of more intuitive display of information, enhancement of training transfer among other Army controls and displays, and minimization of information overload. For example, one operational definition of scalability is "The transmission of critical information to the Soldier tailored for each level of combat to ensure mission success while maximizing survivability by minimizing equipment requirements; minimizing multitasking workload, maximizing situation understanding; and maximizing aerial and ground robotic mission effectiveness" (Merlo, 2006). A similar definition is "The tailored reception and transmission of mission-essential information at the appropriate level for the Soldier, to ensure mission success while maximizing the survivability and lethality through the synergistic interaction of equipment requirements, appropriate cognitive workload, situation awareness and understanding for oneself and others connectivity of distributed intelligent agents" (Barnes, 2006).

In our stream of research, we focus on size, weight, and ease of use for dismounted Soldier applications. Soldiers operate in a large range of environments, from the relatively stable and spacious environment of a tactical operations center (TOC) to the cramped environment of a vehicle to the rugged and challenging environment of the dismounted Soldier. All these environments have an impact on the effective size and configuration of the robotic interface. A dismounted Soldier cannot carry the relatively large controller that can be used in a TOC. Small input devices are quite different from larger ones and can potentially impact the complexity of operation, the speed of operation, and the accuracy of input. Designing for the "optimum" input device size may seem to be a good idea because the presentation of the interface may seem to be controlled. However, if an input device is designed that is only practical in one environment, it may be completely unusable in another.

Certainly, smaller devices that weigh less are usually preferred by dismounted Soldiers. The question is how best do we accomplish controller size reduction? Tele-operation of robotic vehicles is a difficult task because robots are complex machines, typically consisting of a large number of components. Many of the robotic components provide feedback to the operator and require input from the operator. Typically, the controller consists of at least two joysticks or comparable controls for robotic navigation and camera control. In addition, there are many buttons and switches and one or more video screens. Space to incorporate controls on small controllers is very limited.

Miniaturizing individual controls is one option for reducing the size of controllers, but Soldiers have to be able to operate controllers while wearing gloves without accidentally activating adjacent controls. One benefit of the miniaturization approach is that if we simply make existing controllers smaller, the similarity of controls should enhance transfer of training. However, how small can we go before the buttons and spacing are too difficult for operational performance? Another option is to reduce the number of individual controls on controller devices by incorporating multifunction controls (controls that can perform different functions, depending on the current mode of operation). For example, a driving joystick can become a camera pan-and-tilt controller when the system is placed in another mode of operation. However, multifunction controls may increase control activation time and cognitive complexity. The end result could be that a controller with multifunction controls may require many hours of training before a user is competent and comfortable enough to use the system during a real mission. Other creative approaches to controller size reduction that have been developed are sketch interfaces (Skubic, Bailey & Chronis, 2003; Setalaphruk, Ueno, Kume, & Kono, 2003), voice recognition and synthesis systems (Chen, Haas, Pillalamarri, & Jacobson, 2006), and hands-free systems (Veronka & Nestor, 2001), but these novel controls often present problems of their own and they are still being refined.

In the meantime, there is an immediate requirement for dismounted Soldier robotic tele-operation controllers and not much empirical data about the impact of size reduction. In this experiment, we chose three different types of controllers and demonstrated their potential for use by a dismounted Soldier to control a small robotic platform and its sensor payload. One of the controllers was the default controller for the robot used in this study. We also included two controllers that reflected near-term options for scaling controllers for the dismounted Soldier. All controllers were compared on the same set of measures. Pre-test experimentation was performed to ensure that the functional mapping of each of the controllers was effective as possible. The trade-offs between interface size and weight with these controllers versus input speed, accuracy, training time, and cognitive load were examined.

1.2 Overview of Experiment

This study was an investigation of the effect of controller size scalability on robotic control. It took place at Fort Benning, Georgia, with 12 Soldiers from the Officers' Candidate School (OCS) and three Soldiers from Headquarters Company 1st Battalion 11th Infantry Regiment as

participants. Before any training, an intuitiveness evaluation was conducted on each controller. After training in the operation of the IRobot[1] PackBot[1] Robot system, each Soldier completed a driving course using three different controller types. The terrain and hazards were counter-balanced along with the controller type to control for the effect of learning. Workload for each controller was measured by having the Soldiers complete the National Aeronautics and Space Administration (NASA) Task Load Index (TLX) survey after they completed the driving course. Controller type and usability were evaluated, based on objective performance data, data collector observations, and Soldier questionnaires.

1.3 Objectives

There were two objectives in this experiment. The primary objective was to determine whether differences among the controller design approaches had any effect on the operation of a small robot. The second objective was to conduct an intuition test of the controller design and function mapping of each controller.

2. Method

2.1 Participants

Twelve Soldiers from the OCS and three Soldiers from Headquarters Company 1st Battalion 11th Infantry Regiment participated in the study.

2.1.1 Pre-test Orientation and Volunteer Agreement

The Soldiers were given an orientation about the purpose of the study and their participation. They were briefed about the objectives and procedures, as well as the robot. They were also told how the results would be used and the benefits the military could expect from this investigation. Any questions the subjects had regarding the study were answered. It was made clear that Soldier participation in the experimentation was voluntary. The volunteer agreement affidavit was explained and its contents verbally presented. The Soldiers were given the volunteer agreement affidavit to read and sign if they decided to volunteer.

2.1.2 Medical Review and Screening

The Soldiers were given a medical status form to determine if any of them had a medical profile or history that would jeopardize them if they participated in the study.

[1]iRobot and PackBot are registered trademarks of iRobot Corporation, Burlington, Massachusetts.

2.2 Instruments and Apparatus

2.2.1 IRobot PackBot Explorer Robot

The IRobot PackBot Explorer Robot (figure 1) is a portable small unmanned ground vehicle (SUGV) reconnaissance and tactical robot that can enter and secure areas that are inaccessible or too dangerous for humans. The IRobot PackBot Explorer Robot payload has a rotating pan-and-tilt head equipped with multiple cameras.

2.2.2 Robotic Vehicle Controllers

The three controller types used during this experiment are listed in table 1. Controller A was the largest of the three controllers, and each control manipulation had a single function. Controllers A and B had the same number of single-function controls; however, controller B's controls were placed in a different configuration and were smaller than controller A's. Controller C attached to the bottom rail of the M4 in the same fashion as a forward hand grip. Controller C had the fewest controls, and the controls had multi-functionality. Controllers A and B were designed to be operated with both hands, while controller C was designed for single-handed operation. Pictures of the three controllers are shown in figures 2 through 4.

Figure 1. IRobot PackBot explorer robot.

Table 1. Controller data.

Controller Label	Controller Name	No. of Possible Control Manipulations	Controller Weight (lb)	Controller Dimensions (LxWxH in.)
A	Legacy Controller	30	1.40	8.5 x 4.25 x 4.25
B	Logitech Controller	26	.56	6 x 4 x 2.38
C	Q3D Controller	11	.65	6 x 2.63 x 7

DOCU for Explorer:
Mappings
(Legacy Controller)

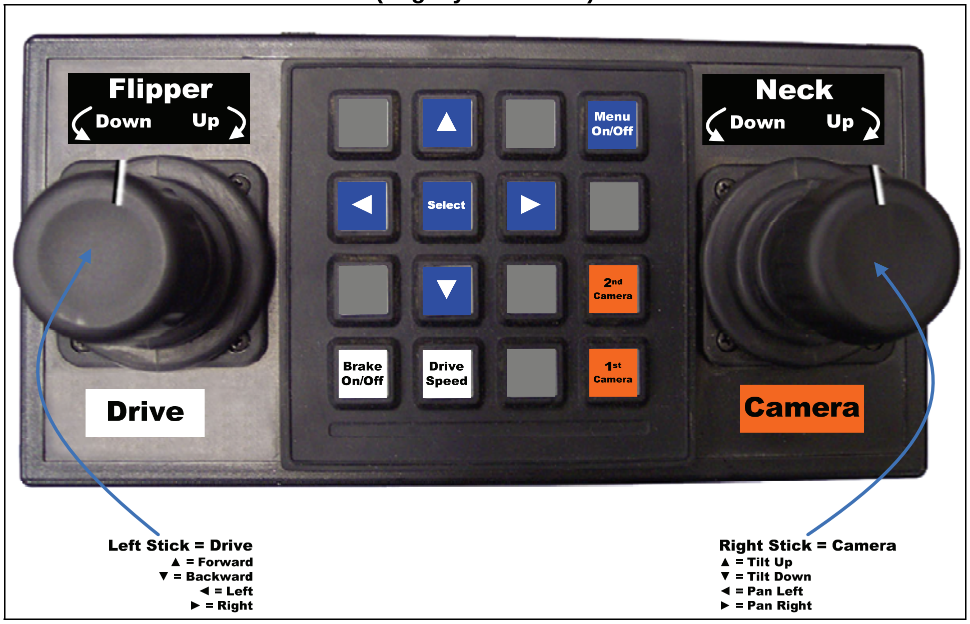

Figure 2. Controller A.

DOCU for Explorer:
Mappings
(Logitech[2] Controller)

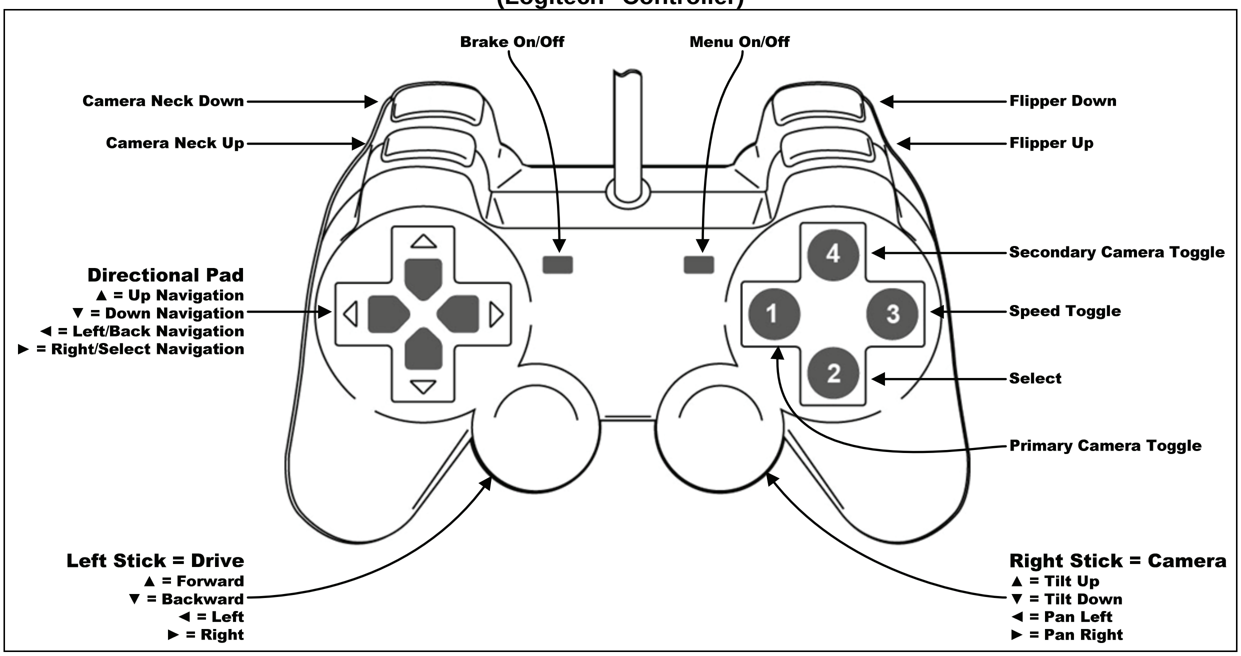

Figure 3. Controller B.

[2]Logitech is a registered trademark of Logitech, Inc.

Figure 4. Controller C.

2.2.3 Control Intuitiveness Test

The control intuitiveness test performed in this experiment was roughly based on an icon intuitiveness study done by Nielsen and Sano (1994), which was performed during the usability evaluation of Sun Microsystems' internal web. Nielsen and Sano presented images to users who were then asked to indicate what functionality they thought the icons represented. In the present study, we presented a task (i.e., raise the arm of the sensor head, raise the flippers, drive the robot forward, brake, pan the camera to the left) to the Soldiers who had no prior training or use of the controller and then asked them to perform the task. The administrator documented the number of correct and incorrect attempts to perform the task and noted the specific controls that were incorrectly activated.

2.2.4 Robotic Course

The experiment was conducted on a driving course approximately 200 meters long (figure 5). The driving lane on the course was approximately 1 meter wide and clearly marked with white engineer tape on the left and right sides. Along the course were seven stations where the operator conducted a specified maneuver or reconnaissance task. The seven stations were stair ascend/descend; window reconnaissance; target identification/tracking; hill climb; bunker reconnaissance; tunnel reconnaissance; and zigzag negotiation. Soldiers tele-operating the IRobot PackBot were situated at a remote stationary position inside a tent. The tent kept the operator and the controller equipment out of the elements. A description of each station and instructions for executing them follow:

- Station 1. Stairs (Maneuver). The stairs are made of wood. Five steps lead up to a platform and five steps lead down. In order to ascend and descend the stairs, the operator must correctly position the robot flippers to obtain the appropriate angle and control the robot's speed throughout the maneuver.

- Station 2. Window (Maneuver/Reconnaissance). The operator's task at this station is to locate and identify the simulated improvised explosive device (IED) hidden behind the urban wall. Upon reaching the wall, the operator must back the robot into position below the window, extend the sensor head arm, and maneuver the sensor head in order to see through the window opening. The operator locates and identifies to the data collector a pipe bomb, ammunition can bomb, or soda can bomb.

- Station 3. Target Tracking (Maneuver/Reconnaissance). The operator positions the robot at the row of sandbags and locates the human target. The operator zooms in on the human target and identifies the object he is holding as a sledge hammer, M4 carbine, shovel, or box. The human target is then cued by the data collector to start walking perpendicular to the robot. At set intervals along the route, the human target discards the object and replaces it with a different object. The operator is required to track the target and report to the data collector what the target is carrying at all times throughout the exercise.

- Station 4. Hill (Maneuver). The hill is approximately 10 m long, 1 m wide, and 3 m tall with a 30-degree sloped incline and decline. The operator must control the robot's direction and speed throughout the maneuver.

- Station 5. Bunker Reconnaissance (Foxhole) (Maneuver/Reconnaissance). The operator's task at this station is to locate and identify the simulated IED marked with an alphanumeric label hidden in a partially covered foxhole. Upon reaching the foxhole, the operator must back the robot into position, extend the sensor head arm, and maneuver the sensor head in order to see through the foxhole opening. After the operator locates the IED, s/he must use the camera zoom feature and report the alphanumeric label to the data collector.

- Station 6. Tunnel (Maneuver). The tunnel is a culvert pipe 6 m long by 1 m in diameter and made of corrugated steel. The operator aligns the robot with the tunnel opening and maneuvers the robot through the pipe.

- Station 7. Zigzag (Maneuver). The zigzag is 1.6 m tall, 14 m long, and approximately 1 m wide. It consists of three turns (approximately 90 degrees each) within the lane. The framework is constructed of wood with mesh wire installed between the two lanes and on the outside framework of each lane. The operator maneuvers the robot through the zigzag, controlling both speed and direction.

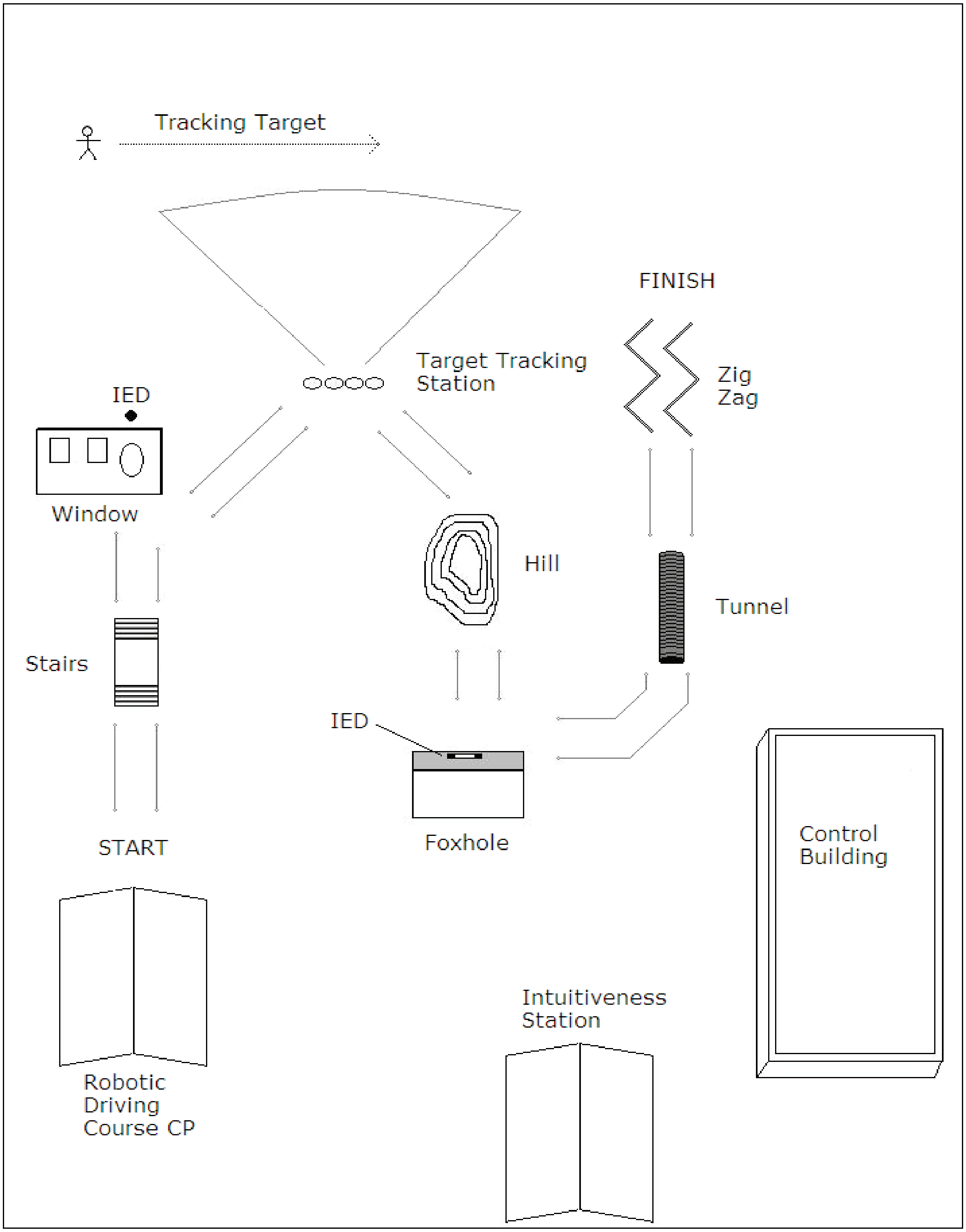

Figure 5. Robotic driving course.

2.2.5 NASA TLX

The NASA TLX requires the user to rate the workload of a device on a number of different scales and to assign an importance weight to each scale. The scores on the workload scales (mental, physical, temporal, performance, effort, and frustration) can be combined in an overall workload score (Hart & Staveland, 1988).

2.2.6 Questionnaires

The questionnaires were designed to elicit Soldiers' opinions about their performance and experiences with each of the controller systems. The questionnaires asked the Soldiers to rate the devices on a 7-point Likert scale ranging from "extremely bad/difficult" to "extremely good/easy". Questionnaires were administered to each Soldier at the end of each iteration and at the end of the experiment. Questionnaires were also used to gather information concerning the Soldiers' demographic data, robotic experience, and physical characteristics that might affect their ability to operate the robot.

2.3 Procedures and Methodology

2.3.1 Soldier Orientation

The experiment Soldiers reported in groups of three for one day each, 0800 to 1800 daily. They then received a roster number, which was used to identify them throughout the evaluation. After their pre-test orientation, the volunteer agreement affidavit was explained and its contents verbally presented. Next, the Soldiers were given the volunteer agreement affidavit to read and sign if they decided to volunteer. The volunteers were then asked to complete the medical review and screening form. Demographic data, as well as data concerning their Army and robotic experience and physical characteristics, were also taken for each Soldier. Next, Soldiers received an orientation of the robotics driving course. During the orientation, trainers demonstrated the tasks to be performed at each station. The intuitive test and the training course were also explained and any questions the Soldiers had concerning the experiment were answered.

Soldiers completed three iterations of the four stations (one with each controller type) according to the matrix in table 2. They started at station 1 (the intuitiveness exercise), then moved to station 2 (the training course), then moved to station 3 (the robotic course), and finally moved to station 4 (the questionnaire station). After the third iteration, they completed an end of experiment questionnaire.

Table 2. Order of treatments.

Roster (Soldier)	Iteration		
	1	**2**	**3**
1	A	B	C
2	B	C	A
3	C	A	B
4	C	B	A
5	B	A	C
6	A	C	B
7	A	B	C
8	B	C	A
9	C	A	B
10	C	B	A
11	B	A	C
12	A	C	B
13	A	B	C
14	B	C	A
15	C	A	B

2.3.2 Control Intuitiveness Station

At the intuitiveness station, Soldiers were given a controller with all labels covered or removed and were asked to activate the control that they thought would most likely cause the robot to perform a specified task. Soldiers were then asked why they selected the control. Five tasks were selected for the test: raise the arm of the sensor head, raise the flippers, drive the robot forward, brake, and pan the camera to the left. Soldiers were given three attempts to select the correct control and were asked after each selection why they selected it. If a Soldier selected the correct control, s/he moved to the next task. The administrator documented the number of incorrect attempts to perform the task, noted the specific controls that were incorrectly activated, and recorded the Soldier's feedback concerning why each control input was chosen. After the Soldiers completed the tasks with all three controllers, they were asked to complete a questionnaire designed to elicit information about the intuitiveness of each controller's design.

2.3.3 Training Station

A representative from iRobot trained the Soldiers to use the IRobot PackBot. Soldiers practiced tele-operating the robot on the actual course used during the experiment. They were trained on each controller just before executing the robotic course with that controller. The course required driving, obstacle negotiation, sensor head manipulation, target identification, and moving target tracking. It also involved training in the graphical user interface (GUI), use of the video cameras, and use of the robotic flippers to negotiate obstacles such as stairs and low walls. Soldiers were trained on each controller for 30 minutes. During pilot testing, it was found that 30 minutes of hands-on training with each controller was adequate for Soldiers to become proficient in performing the various tasks required to complete the driving course. Upon completion of the training, the Soldiers negotiated the robotic driving course.

2.3.4 Robotic Driving Course

Soldiers negotiated the robotic driving course by tele-operating the robot using the three controller types. The course required driving, obstacle negotiation, sensor head manipulation, target identification, and moving target tracking.

The robotics course was approximately 200 m long and had seven stations along its route (see table 3). The Soldiers were told to maneuver the robot along the course marked with engineer tape and to conduct a reconnaissance at key locations along the route. At each station, the operator was instructed to perform a specified maneuver or reconnaissance task. A data collector following the robot recorded the time required for the Soldier to complete each station, driving errors, and the number of times the robot was driven off course. A driving error was defined as running into objects on the course or failing to properly position the robot to perform the task required at a station. Off course was defined as major off course or minor off course. A major off course was recorded if the robot went completely outside the engineer tape and a minor off course was recorded when only a portion of the robot crossed the tape. An additional data collector was co-located with the Soldier to observe and record the Soldier's responses and to record overall course completion times.

Table 3. Robotic course stations.

Station	Description	Task
Station 1	Stair Ascend/Descend	Maneuver
Station 2	Window Target	Maneuver/Reconnaissance
Station 3	Area Scan/moving target	Maneuver/Reconnaissance
Station 4	Hill	Maneuver
Station 5	Bunker Reconnaissance (Foxhole)	Maneuver/Reconnaissance
Station 6	Tunnel	Maneuver
Station 7	ZigZag	Maneuver

Upon completion of the course, the Soldiers were given a questionnaire designed to assess their performance and experiences with each of the control systems and to assess their perception of the training adequacy. Questions about the amount of practice time given, the level of detail presented, and the adequacy of training aids were included.

2.3.5 End of Iteration Questionnaire Administration Station

End of iteration questionnaires and the NASA-TLX were administered to each Soldier at the end of each iteration. After completing the course with each of the three controller types, the Soldiers completed an end of experiment questionnaire that compared each of the controller types for a number of characteristics. They also completed questionnaires concerning the information requirements for tele-operating the robot.

2.4 Experimental Design

This experiment used a within-subject design, with treatments counterbalanced to control for sequence effects.

2.4.1 Independent Variable

- Controller type

2.4.2 Dependent Variables

- NASA TLX workload scores,
- Robotic course completion time,
- Time to complete each station on the course,
- The number of major times the driver went off course,
- The number of minor times the driver went off course,
- The number of driving errors on the course,
- Number and type of errors committed during each task of the intuition test,
- Data collector comments, and
- Questionnaire responses.

2.5 Data Analysis

All objective data were analyzed with a repeated measures analysis of variance (ANOVA). Follow-on pair-wise comparisons were done with Holm's Bonferroni procedures to control for family-wise error rates. Partial η^2 (η^2_p), an index of effect size, was computed for each ANOVA. Iteration effects were controlled through the counterbalanced order of the experimental design. Soldier questionnaire data were analyzed with the use of descriptive statistics on the subjective ratings.

3. Results

3.1 Demographics

The rank of the enlisted Soldiers ranged from E-3 to E-7, with one chief warrant officer in the rank of CW3. Their average time in service was 69 months. Two of the Soldiers wrote with their left hand and all 15 Soldiers fired their weapons right handed. Nine of the Soldiers had

driven a remote controlled car, but none had ever operated a robotic vehicle. All but three of the Soldiers played video games on a regular basis. Detailed results are presented in appendix A.

3.2 Control Intuitiveness

The results from the intuitiveness test were weighted based on the number of attempts to find the correct control. Three points were given for the first selection, two for the second, and one for the third. Therefore, the higher weights represent the most intuitive control mapping and the lower weights represent the least intuitive.

The following three figures show each controller with the controls labeled with numbers used to identify which control the Soldiers selected during the intuitiveness test. The following three tables show the tasks, the control with the highest intuitiveness weight, and the weight given for the control currently mapped to perform the task. The complete list of responses (including those that did not receive the highest weightings) are presented in appendix B.

3.2.1 Controller A

The controls on controller A labeled 2 through 17 are actuated by buttons; 1A through 1F and 18A through 18F are actuated by toggle manipulations (figure 6). Results for controller A (table 4) show that the current controller mappings for raising the arm of the sensor head (18E) and raising the flippers (1F) were not selected as the most intuitive control manipulations to perform these tasks. Soldiers justified their selections, based on the assumption that the toggles were mapped for important functions such as driving and camera manipulations. The current mapping for driving the robot forward, applying brakes, and panning the camera left were weighted as the most intuitive control manipulations for these tasks. Detailed results are presented in appendix B.

Figure 6. Controller A with labels.

Table 4. Controller A weighted scores.

Task	Control Selected (figure 6)	Weighted Score
1. Raise the arm of the sensor head.	2	13
	18A	13
	18E*	2*
2. Raise the flippers	2	11
	1F*	3*
3. Drive the robot forward.	1A*	37*
4. Brake	14*	12*
5. Pan the camera left	18C*	17*

* = Currently mapped control

3.2.2 Controller B

The controls on controller B (figure 7) labeled 1 through 8 and 11 through 18 are actuated by buttons; 9A through 9D and 10A through 10D are actuated by toggle manipulations. Results for controller B (table 5) show that the current controller mappings for raising the arm of the sensor head (2) and applying brakes (7) were not selected as the most intuitive control manipulations to perform these tasks. Soldiers based their selection of 10A for raising the sensor head on the assumption that the toggles should control the camera and 14 for braking based on the assumption that the directional pad should control the robot's speed. The current mappings for driving the robot forward, raising the flippers, and panning the camera left were weighted as the most intuitive control manipulations for these tasks.

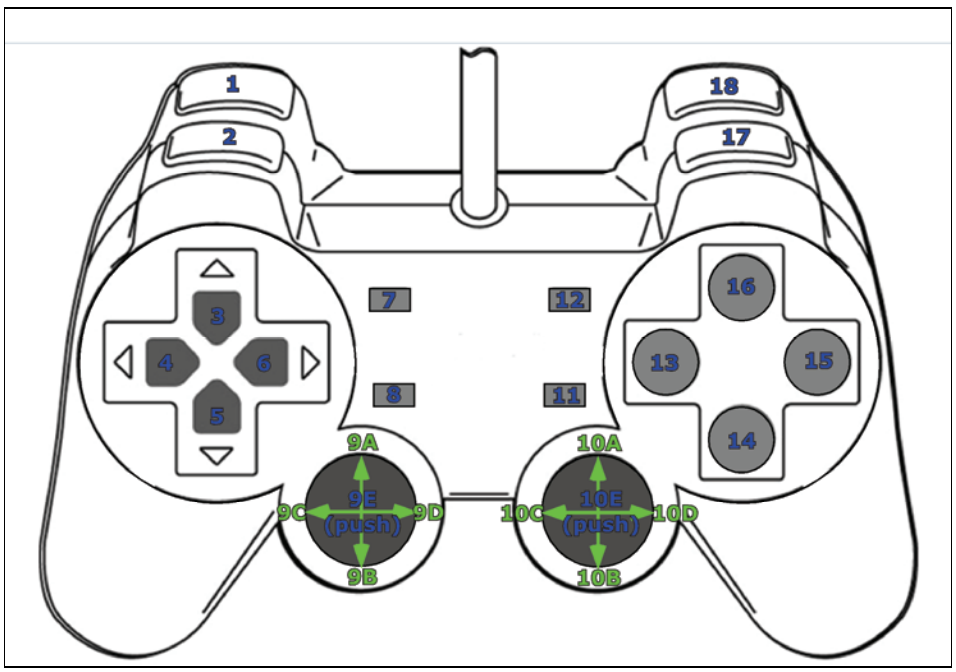

Figure 7. Controller B with labels.

Table 5. Controller B weighted scores.

Task	Control Selected (figure 7)	Weighted Score
1. Raise the arm of the sensor head.	10A	16
	2*	12*
	17*	22*
2. Raise the flippers	9A*	36*
	14	18
3. Drive the robot forward.	7*	5*
4. Brake	10C*	21*
5. Pan the camera left	10A	16

* = Currently mapped control

3.2.3 Controller C

The controls labeled 2 through 5 on controller C (figure 8) are buttons; 1A through 1E are actuated by a toggle, and 6A and B are actuated when the hand grip on the control is twisted. Results for controller C (table 6) show that the current controller mapping for raising the arm of the sensor head (1D) was not selected as the most intuitive control manipulation to perform the task. Soldiers stated that raising and lowering the arm of the sensor head should be accomplished by pushing up or down on the toggle. The current mappings for raising the flippers, driving the robot forward, applying brakes, and panning the camera left were weighted as the most intuitive control manipulations for these tasks.

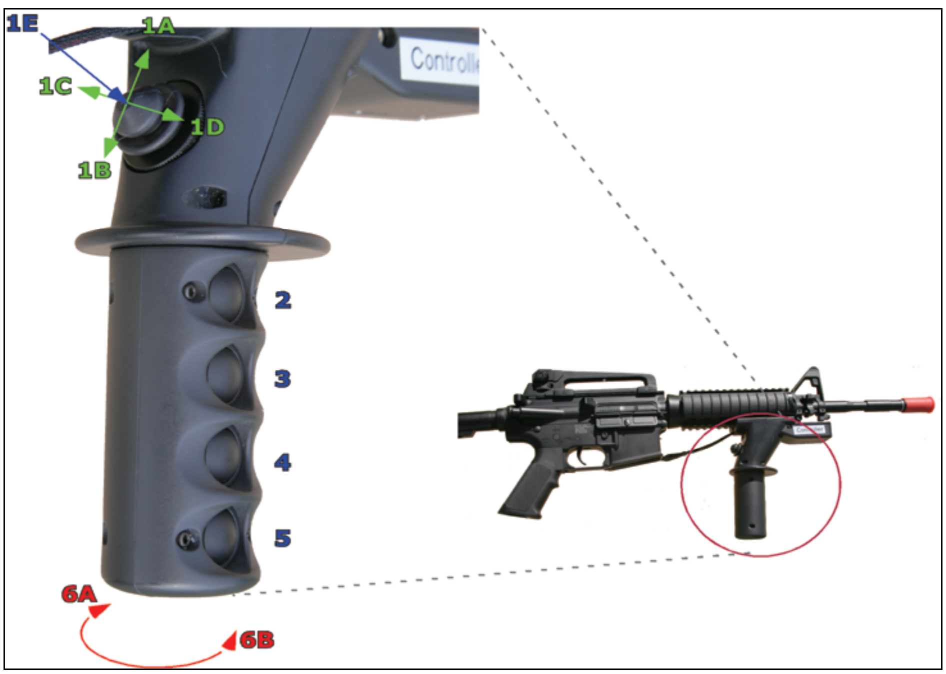

Figure 8. Controller C with labels.

Table 6. Controller C weighted scores.

Task	Control Selected (figure 8)	Weighted Score
1. Raise the arm of the sensor head.	1A	34
	1D*	2*
	1A*	21*
2. Raise the flippers	1A*	39*
	5*	18*
3. Drive the robot forward.	1C*	43*
4. Brake	1A	34
5. Pan the camera left	1D*	2*

* = Currently mapped control

3.2.4 Summary

Table 7 and figure 9 show the proportion of correct responses (choice of the currently mapped control) to each command for the three controllers. A correct response is defined as the response being correct on the first, second, or third choice. The differences in proportion of total correct responses between the three controllers is statistically significant: $\chi^2 = 9.90$, df = 2, $p < .01$. One reason for the higher proportion of correct responses with the C controller is that there are only 11 possible responses with the C device, as opposed to 30 possible responses with the A controller and 26 possible responses with the B controller.

Table 7. Proportion of correct responses.

Task	Controller (percent)		
	A	B	C
1. Raise the arm of the sensor head	3	16	3
2. Raise the flippers	3	26	29
3. Drive the robot forward.	74	52	100
4. Brake	21	7	25
5. Pan the camera left	28	30	82

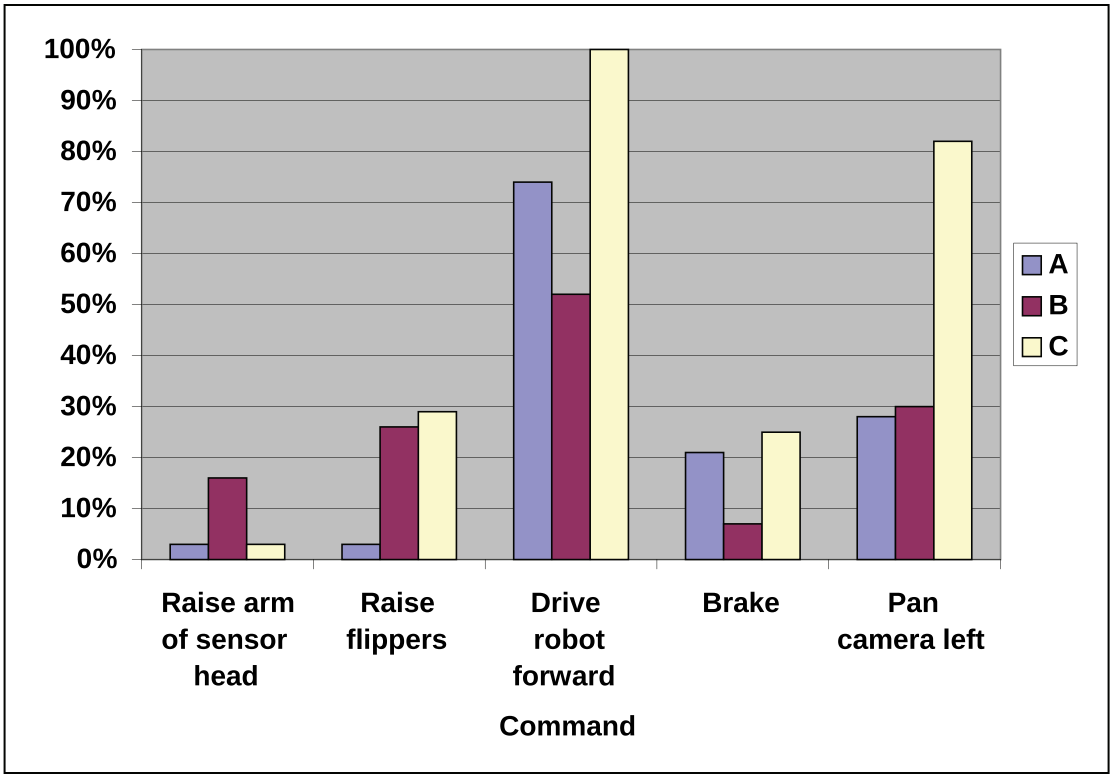

Figure 9. Proportion of correct responses.

3.3 Training

The Soldiers' overall ratings of the training course were between good and extremely good for all three controllers. Most test Soldiers rated the C controller as more difficult to learn than the A and B controllers primarily because they had to learn the different functions (modes) for each control. Controlling the camera and adjusting to the controllers' sensitivities were identified as tasks that were difficult to learn for all three controllers. Soldiers commented that the 30 minutes allowed to train with each controller was adequate time for learning to negotiate the course. Detailed training questionnaire results are presented in appendix A.

3.4 Robotic Course

Table 8 and figure 10 show the mean course completion times for the three controllers. The error bars in the graph represent 95% confidence intervals. A repeated measures ANOVA indicated that there was a significant difference among the means: $F(2,24) = 7.07$, $p = .004$, $\eta^2_p = .371$. Follow-on pair-wise comparisons were conducted with Holm's Bonferroni sequential correction for family-wise error rates. As shown in table 9, the average course completion time for controller C was significantly slower than the average times for controllers A and B. The time required to switch function modes and the limited ability to perform simultaneous tasks when Soldiers were tele-operating the robot using controller C were identified as the primary reasons for its slower completion times. Performing some tasks simultaneously with controller C, such as driving the

robot forward while raising the sensor arm, is not possible because Soldiers have to switch modes of the multifunction controls.

Table 8. Mean course completion times.

Controller	Mean	*SD*
A	16:17	*3:44*
B	16:07	*5:49*
C	20:35	*3:37*

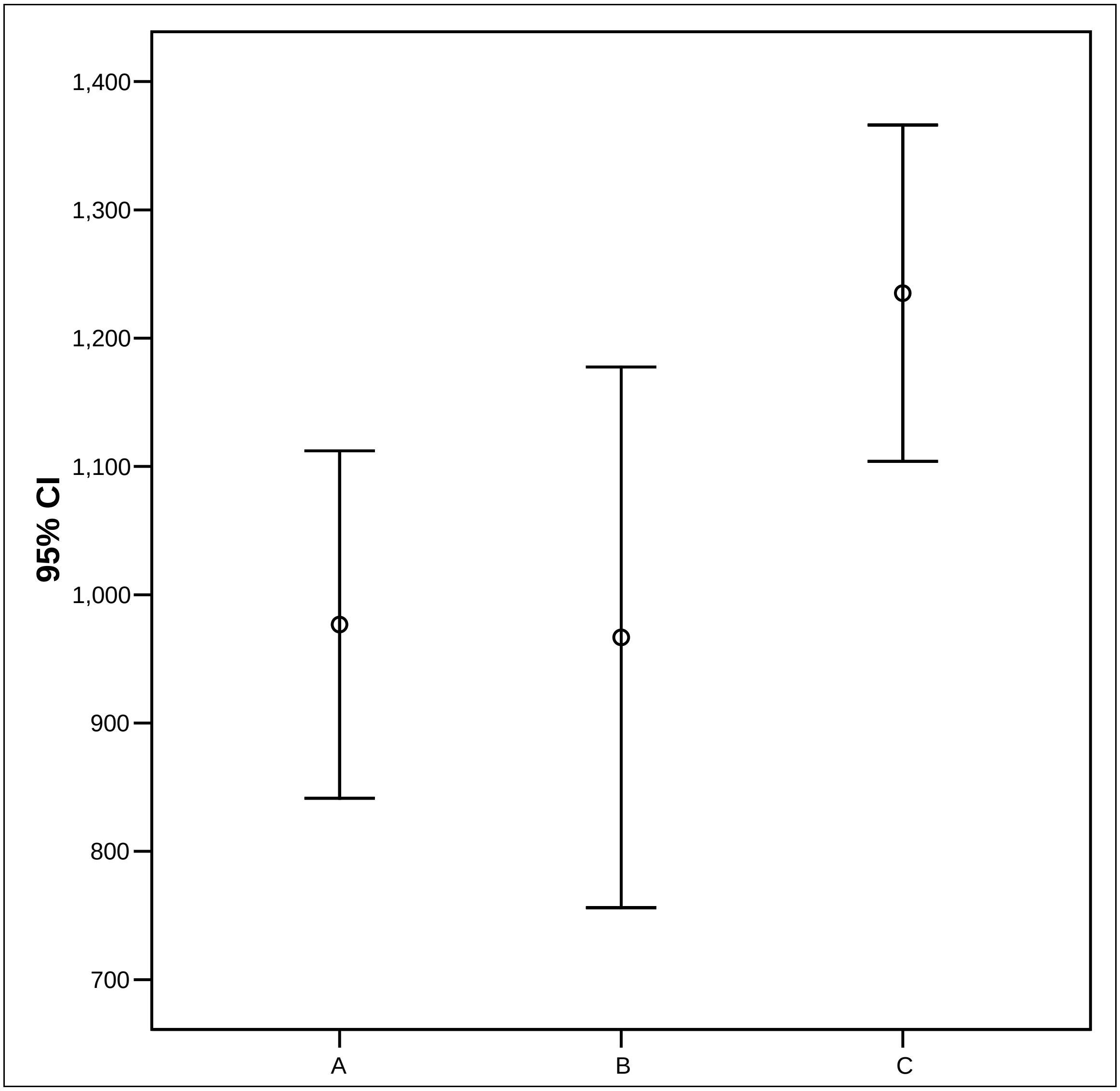

Figure 10. Mean course completion times (seconds).

Table 9. Follow-on comparisons, course completion times.

Pair	***T***	**df**	**obtained *p***	**required *p***
A vs. B	0.22	14	0.827	0.05
A vs. C	-3.84	12	0.002*	0.0167
B vs. C	-2.84	12	0.015*	0.025

* $p < .05$, 2-tailed

Table 10 shows the mean number of major off-course errors. There were too few major errors to conduct a repeated measures ANOVA.

Table 10. Mean major off-course errors.

Controller	**Mean**	***SD***
A	2.00	*0*
B	1.67	*0.52*
C	1.67	*0.58*

The mean numbers of minor off-course errors for the three controllers are shown in table 11. There was no statistically significant difference among the means: $F(2,14) < 1.00$, $p = .639$, $\eta^2_p = .062$.

Table 11. Mean minor off-course errors.

Controller	**Mean**	***SD***
A	4.13	*4.64*
B	4.88	*2.70*
C	3.38	*1.51*

The average numbers of driving errors between stations for each controller are shown in table 12. There was no statistically significant difference among the means: $F(2,16) = 1.17$, $p = .336$, $\eta^2_p = .128$.

Table 12. Mean driving errors.

Controller	**Mean**	***SD***
A	4.11	*5.04*
B	6.22	*2.82*
C	4.00	*2.18*

Soldiers were able to successfully perform all the driving and reconnaissance tasks presented on the robotic driving course using all three controllers. Upon completion of each iteration, Soldiers were asked to rate the characteristics of the controller they had used and their ability to perform various tasks while maneuvering through the driving course. When asked to rate the characteristics of each controller, Soldiers rated controller B highest for size, weight, shape, comfort of use, and location of individual controls. Several Soldiers stated that controlling the robot's rate of speed and

direction using the B controller was difficult because of the sensitivity of its driving controls. Soldiers stated that the large size of controller A's controls allowed them to be labeled and made finding the correct control easy.

Performing multiple tasks simultaneously (i.e., raising the control arm while tilting the sensor head) was rated as very difficult with the C controller. Controlling more than one robotic task simultaneously with one hand requires more dexterity than when the tasks are performed with both hands. Several Soldiers reported that they experienced wrist, arm, hand, and finger strain when operating the C controller. Supporting the weight of the weapon while manipulating the controller and performing all tasks with one hand were identified as the primary reasons Soldiers were experiencing strain. Detailed Soldier questionnaire results for the driving course are presented in appendix A.

3.5 NASA TLX

Table 13 shows the weighted means for each of the TLX scales, as well as the weighted means for the total workload score. The scale score means are illustrated in figure 11. The graph clearly indicates that the mental activities formed the greatest portion of task workload. The C controller has a slightly higher mean workload rating than controllers A or B in terms of mental demands, effort, and frustration.

Table 13. Weighted means, NASA workload scales.

	Mental		Physical		Temporal		Performance	
Controller	**Mean**	***SD***	**Mean**	***SD***	**Mean**	***SD***	**Mean**	***SD***
A	13.2	*9.2*	0.5	*0.9*	4.1	*2.6*	8.0	*7.2*
B	13.3	*7.6*	1.2	*3.1*	6.2	*7.0*	6.8	*6.6*
C	17.3	*9.1*	2.2	*2.9*	6.2	*6.2*	5.8	*5.3*

	Effort		Frustration		Total	
Controller	**Mean**	***SD***	**Mean**	***SD***	**Mean**	***SD***
A	6.5	*5.3*	4.3	*5.3*	36.6	*13.5*
B	5.3	*4.7*	7.0	*9.1*	39.7	*16.1*
C	8.7	*5.8*	9.5	*10.6*	49.7	*23.8*

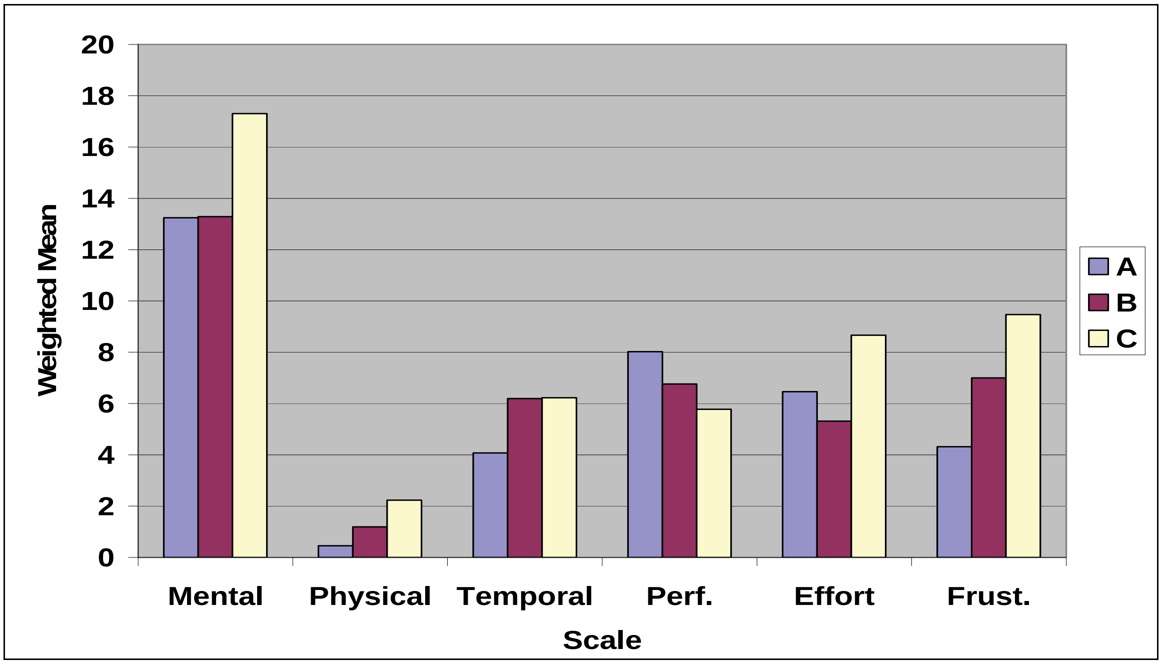

Figure 11. Mean NASA TLX scale scores.

Repeated measures ANOVAs were used to compare the weighted means for each of the workload scales. The results are summarized in table 14. The difference among the controller means was significant only for the total scale.

Table 14. ANOVA summary, NASA TLX scales.

Scale	df	F	*p*	η^2_p
Mental	2,28	2.77	0.080	0.165
Physical	2,28	3.24	0.054	0.188
Temporal	2,28	1.27	0.297	0.083
Effort	2,28	< 1.00	0.638	0.032
Performance	2,28	1.92	0.165	0.121
Frustration	2,28	1.97	0.158	0.123
Total	2,28	3.93	0.031*	0.219

* $p < .05$

The follow-on pair-wise comparisons for the total scale are summarized in table 15. Although none of the pair-wise differences were statistically significant, the difference between controllers A and C approached statistical significance.

Table 15. Follow-on comparisons, total NASA-TLX.

Pair	*t*	df	obtained *p*	required *p*
A vs. B	-1.09	14	0.296	0.05
A vs. C	-2.62	14	0.020	0.0167
B vs. C	-1.62	14	0.127	0.025

3.6 End of Experiment Questionnaire Results

Most Soldiers felt that controller A was the quickest and easiest to use because of its size and control layout. Controller B was selected by most Soldiers as the most comfortable controller to use because of its size, weight, and design. Controller C was selected as the easiest to carry on a mission since it attaches directly to the weapon. Soldiers commented that they would like the ability to set the sensitivity level for each controller, based on the difficulty they experienced controlling the robot's rate of speed and problems encountered with over-steering when maneuvering.

Soldiers felt that reducing a controller size by shrinking the size of the individual controls would impact performance less than reducing its size by reducing the number of controls. Soldiers indicated that the multifunction controller was more difficult to learn and use than the controller with reduced control sizes and that switching between functions was time consuming and confusing. Detailed end of experiment questionnaire results are presented in appendix A.

4. Conclusions

The primary objective of this study was to evaluate controller devices that differ in features relevant to scaling robotic control devices for the dismounted Soldier. Soldiers were able to successfully perform all the driving and reconnaissance tasks presented on the robotic driving course using all three controllers. The results provide an indication that reducing a controller size by shrinking the size of the individual controls (controller B) had less adverse impact on performance than reducing its size by reducing the number of controls (controller C). However, when one is interpreting the results of this experiment, it is important to understand that there were limitations in the availability of controllers that were identical in all aspects (control mappings, sensitivity, etc.). Thus, uncontrolled variables could have played a role in the outcomes. However, several findings that support this conclusion should not have been impacted by the uncontrolled variables. First, Soldiers reported that the multifunction controller was more difficult to learn and use than the controller with reduced control sizes because switching between functions was time consuming and confusing. This difficulty increased perceived workload, which is a particularly important finding for dismounted operations because Sterling and Perala (2007) found that robotic controllers supporting infantry units had higher workloads and stress than controllers supporting other types of units. Second, Soldiers found that several robotic control functions could not be performed simultaneously (e.g., raise the control arm while turning the sensor head) with the multifunction controller. This necessitated sequential operation which was time consuming and difficult. Therefore, despite the uncontrolled variables, the conclusion that miniaturization provides less adverse impact on performance reduction of the number of controls appears to be a valid one.

The intuitiveness test used during this experiment to evaluate the control mapping performed on the controllers shows promise as an evaluation technique. It would be especially useful as a quick and easy way to use target audience Soldiers to evaluate different mappings on the same controller.

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Appendix A. Soldier Questionnaire Results

DEMOGRAPHICS

SAMPLE SIZE = 15

RANK	MOS		DUTY POSITION	AGE
E-3 - 1	11B - 1	68W - 2	Rifleman – 1	28 years (mean)
E-4 - 3	13F - 1	92A - 1	OCS – 4	
E-5 - 6	15H - 1	98G - 1	Instructor Pilot – 1	
E-6 - 1	25S - 1	OCS - 2	Medical PSG – 1	
E-7 - 3	25W - 1	NR - 3	S-1 Clerk – 1	
CW3 - 1	42-F - 1		S-3 Clerk – 1	
			S-4 – 1	
			NR – 5	

1. How long have you served in the military? 69 months (mean)
2. How long have you had an infantry-related job? 18 months (mean)
3. How long have you been a fire team leader? 2 months (mean)
4. How long have you been a squad leader? 12 months (mean)
5. How long have you been deployed overseas? 15 months (mean)
6. How long have you been deployed in a combat area? 7 months (mean)
7. Corrected Visual Acuity: 14 20/20 both eyes 0 20/20 in one eye 1 other: 20/60
8. Please list any visual problems which you may have. None (other than corrective lenses).
9. Height: 69 inches (range is 60-76)
10. Weight: 169 pounds (range is 143-210)
11. With which hand do you most often write? 13 Right 2 Left
12. With which hand do you most often fire a weapon ? 15 Right 0 Left
13. a. Do you wear prescription lenses? 9 No 6 Yes

    b. If so, which? 4 Glasses 2 Contact Lenses
14. Do you wear glasses or contacts while firing a weapon? 9 No 6 Yes
15. Which is your dominant eye? 11 Right 4 Left
16. Have you ever driven a robotic vehicle? If yes, describe. 15 No 0 Yes
17. Have you ever driven a remote control car? 4 No 9 Yes 2 NR

18. Using the scale below, please rate your level of experience with the following computer software and computer related activities.

1	2	3	4	5	6	7
No experience	Below average	Slightly below average	Average	Slightly above average	Above average	Expert

	MEAN RESPONSE
a. Microsoft Windows 98, 2000, XP, etc.	4.80
b. Computer based games	4.27
c. Army digital systems (e.g. FBCB2)	2.53
d. I would self rate my computer skills as:	4.73

19. Using the scale below, please rate the following Self-rating of Knowledge, Skills, and Abilities (KSAs) related to Infantry duties.

1	2	3	4	5	6	7
No experience	Below average	Slightly below average	Average	Slightly above average	Above average	Expert

	MEAN RESPONSE
a. Knowledge of tactics, techniques, and procedures (TTP).	3.87
b. Knowledge of map reading and orientation in field setting.	4.53
c. Knowledge of reconnaissance, surveillance, and target acquisition procedures.	2.87
d. Knowledge relating to communications equipment and communications procedures.	3.73
e. Communication skills (ability to use communications equipment and face-to-face communications to enhance mission accomplishment).	4.27

20. How often do you play video games?

_3_ Never _5_ 1-11 times per year _3_ 1-3 times per month _2_ 1-6 times per week _2_ Daily

21. List the games you play regularly from 1 (most frequent) to 5 (least frequent).

1. Counter strike, John Madden, Halo (2), Medieval Total War, Rise of Nations, Tetris
2. Day of Defeat, NCAA Football, Project Gotham Racing 3, WarCraft, Halo, Command/Conquer2, Gran Trurismo
3. Halo, NCAA Basketball, Sudoku, Age of Empires II, Solitaire, Command/Conquer Generals, Grand Theft Auto
4. MLB Baseball, Brain Age, Morrowind, Dominoes, Oblivion
5. NHL Hockey, Everquest, Chess, Lego Starwares 2

POST ITERATION

SAMPLE SIZE = 15

1. Using the scale below, please rate the training that you received on the controller in the following areas:

1	2	3	4	5	6	7
Extremely bad	Very bad	Bad	Neutral	Good	Very good	Extremely good

TRAINING TOPICS	**MEAN RESPONSE**		
	A	**B**	**C**
Explanation of how to drive the robot	6.53	6.47	6.20
Time provided to practice driving the robot	6.47	6.40	5.93
Explanation of how to operate the controller	6.67	6.67	6.13
Time provided for explanation of the controller	6.67	6.53	6.07
Difficulty of learning the controller	6.40	5.67	4.40
Explanation of how to complete each station of the course	6.87	6.53	6.67
Evaluation of the practice lane	6.67	6.47	6.33
How well did you expect to perform on the actual course after your training was complete?	5.33	5.27	5.20
Overall evaluation of the training course	6.27	6.20	5.20

2. What were the easiest and hardest training tasks to learn?

Comments	**No. of Responses**
Easiest:	
A	
Overall control.	1
Learning how to operate.	1
What each control did.	1
Climbing the stairs and hill.	1
Driving.	3
Steering.	1
Using the direction controller.	1
Using the controller.	2
Easy layout.	1
Camera control.	1
Camera movement.	1
Moving the robot.	1
Speed control.	1

Comments	No. of Responses
Multi-tasking.	1
Using the selection screen.	1
B	
Self-explanatory.	1
Learning the controller.	1
Buttons easy to remember.	3
Forward movement.	1
Movement and maneuver.	1
Utilizing camera and display.	1
Flippers.	1
Controlling head.	1
Control of robot.	1
Directional control.	1
Controls very well organized.	1
Stationary task (view stationary targets).	1
Use of control sticks for movement.	1
C	
Learning the controller.	1
Driving.	2
Driving over the hill.	1
Taking corners.	1
Steering the control.	2
Automatic drive mode.	1
Moving the body.	1
Thumb stick.	2
Camera.	2
Learning what each button does.	1
Nothing was easy.	1

Hardest:

A	
Following and focusing on moving targets.	1
Learning how the orientation icon was oriented. Sometimes it was facing me, sometimes away.	1
Performing each step.	1
Adapting to the display's lag.	1
Movement (turning).	1
Neck movement.	1
Flipper and neck control.	1
The maze.	1
Tracking eye movement.	1

Comments	No. of Responses
Camera maneuver.	1
Azimuth.	1
Using zoom.	1
Tracking targets.	1
The scrolling of the camera on moving object.	1
B	
Steering.	1
Controlling the speed.	2
Sensitivity.	4
Compensating for lag time on display.	2
Camera.	1
Camera angle.	1
Control turning.	1
All the buttons.	1
No Y axis inversion.	1
Limited tracking ability.	1
Tracking a moving person.	1
The cross of the flipper control and the raising and lowering of arm. The flipper control should be on the side of the drive and the arm control should be on the side of the camera.	1
C	
Backing up the robot into a spot where the camera has the most visibility.	1
Controller hard to move.	1
Camera modes.	1
Camera switching.	1
Controlling the camera.	1
Camera toggle (select).	2
Narrow zigzag hallway.	1
Holding on to the controller.	1
Toggling between different control functions.	1
Learning and switching between modes.	2
Tracking moving targets.	1
GUI.	1

3. What are your comments on the training course?

A	
Excellent.	1
Very simple to understand and learn.	2
Very well set-up and built course.	3
Suitable for real life scenarios.	1

Comments	No. of Responses
Adequate difficulty.	1
Maybe incorporate more use of the camera on moving objects.	1
Put the robot through good range of maneuvers.	1
Misc. tasks allow for different aspects of the robot being able to be used and learned.	1
Could use more obstacles.	1
The lag between control and actual is very disorienting though with time a person can adjust.	1
B	
Very good.	1
Lots of fun!	1
Objectives were clear, instructions kept simple, and tasks useful for real life situations.	1
Good course; covered most, if not all, areas that robot would be used in.	2
Consistent and enables you to use all the features.	1
Good maneuvers for the robot and used all controls.	1
Testing my ability on basic tasks.	1
Much easier after one training period.	1
Needs a little more practice (operator) before testing.	1
Joystick was too sensitive to movement.	1
Incorporate more camera movement tasks.	1
C	
Overall good instruction.	1
Very good course.	4
Very realistic on everyday combat fields.	1
Very easy to get a working knowledge of this system.	1
Good for learning controls.	1
Used a variety of tasks on the robot.	1
Evaluated basic tasks; taught very well.	1
Could be more challenging.	1
The control was fairly simple, but having it on the weapon was not practical.	1
Need a little more training time in the foxhole.	1
The course was more difficult and extremely time consuming.	1
Controller was slippery and failed to go R and L.	1
More tracking of moving targets.	1

4. What did you think about this controller after completing the training course?

A	
Great controller.	1
I liked how the controller was easy to function and easy to learn and operate.	3
Practical setup.	1
Everything is at your fingertips.	1
Very easy to use.	6

Comments	No. of Responses
Easy to multi-task with.	1
Sensitive.	1
Overall, good controller.	1
Good control.	2
Well labeled.	1
Excellent, but I had azimuth issues.	1
Interface was good and the buttons were under utilized. If some of the buttons were used instead of generic arrows/select, it could be more efficient, i.e., zoom in/out.	1
Adequate.	1
Big, bulky.	3
Needs a few improvements.	1
It works, yet the program seemed too overbearing on the computer.	1
Control sticks could be more sensitive.	1
Could not multifunction enough, i.e., flippers and driving.	1
B	
Easy and quick to use.	2
Easiest to use by far.	1
Good size.	1
Easy to reach all controls.	1
Very simple; almost like common gaming controls.	1
The controller was familiar, making the learning curve a little easier.	1
Key placement was intuitive, making learning simple.	2
I liked the ergonomics of it a lot. Makes more sense than the other two.	1
It was OK.	1
I like it, but I would change the drive button.	1
Better fine control (but not inherent in the controller, more in calibration).	1
Limited multifunction.	1
Why waste a whole button on brake? Could be used as a default/home button. For example, I want to go to drive mode with drive camera from anywhere.	1
Acceleration issues with thumb force controller.	1
Way too sensitive.	5
Having the zoom button and the toggle to “track” ,both on the right side, made it difficult to do both tasks simultaneously.	1
Tactically, wouldn’t have positive control of your weapon.	1
Too many unlabeled buttons. The number sequence made it more difficult to remember what each was meant for.	1
Hard for me to control camera (L, R, up, down).	1
C	
Easy to use.	2
Very easy to learn and move.	1
By far the best maneuvering control.	1
Very smooth.	1

Comments	**No. of Responses**
Practical.	1
Ergonomic. Don't change a thing with the controller.	1
Multifunction button with computer screen makes it simple to navigate.	1
Button placement is easy to work with.	1
The one positive is the system being attached to the weapon, but the equipment has a greater chance of getting damaged.	1
It's better as just a hand-held device.	1
Very complicated.	1
Need some grips on the controller so your hand won't slip.	1
I can't see the thumb stick working well when the operator is sweaty. I kept slipping off.	1
Takes too much time to switch between modes. If I was in a hurry, it would have been hard to execute.	1
Camera controller should be inverted.	1
May be some steering bugs.	1
Did not like.	1
Not very good.	1
Sticky and doesn't offer sensitive controls.	1
Speed is not consistent.	1
This controller is terrible, unreliable, and difficult to maneuver.	1

5. Using the scale below, please rate your ability to perform each of the following **control tasks** based on your experience with the controller that you just used.

1	2	3	4	5	6	7
Extremely difficult	Very difficult	Difficult	Neutral	Easy	Very easy	Extremely easy

CONTROL TASKS	**MEAN RESPONSE**		
	A	**B**	**C**
Ascend stairs	5.60	5.80	5.40
Descend stairs	5.93	5.80	5.60
Position robot to look through a window	5.67	5.13	4.33
Scan for targets	5.40	5.33	4.40
Track a target	4.60	4.40	4.53
Zoom in and out with the camera	5.73	5.87	4.53
Maintain control over uneven terrain	5.93	5.20	5.27
Position robot to look in a bunker	5.60	5.53	4.20
Drive through a tunnel	6.33	6.20	5.43
Drive through a confined space (zigzag)	5.07	4.80	4.73
Stay within course limits (engineer tape)	5.13	4.53	5.20
Control robots rate of speed	4.87	3.40	4.40
Raise robot arm	6.40	6.27	4.86
Tilt sensor head	6.00	5.73	4.87

(continued on next page)

(continued)

CONTROL TASKS	MEAN RESPONSE		
	A	B	C
Rotate/pan sensor head	6.20	5.93	4.93
Steer robot while moving forward	4.73	4.13	4.80
Steer robot while moving in reverse	4.64	4.36	4.43
Position robot flippers	6.40	6.40	5.00
Perform multiple tasks simultaneously (i.e. raise arm while tilting sensor head)	5.14	4.71	2.54
Overall ability to perform driving tasks	5.87	5.13	4.87

Comments	**No. of Responses**
A	
Excellent.	1
Easy to operate.	2
Much easier to use.	1
User friendly.	1
Great control on speed.	1
Easy to do the task. I could drive, raise the head, and change cameras all together.	1
This controller made minute changes possible and easy.	1
Size is too bulky.	1
Due to the lag time, there was difficulty adjusting to the drift.	1
Difficult to make slight turns.	2
I had some difficulty with overcorrecting on right and left steering.	1
Never understood how to “tilt” the camera head. The view ended up uneven when trying to track a target. Difficulty keeping it level.	1
Hardest part was trying to do multiple tasks, i.e., tracking targets while tilting head up and down.	
The falling of the flippers and having to raise them over and over again while traveling over flat ground detracted from concentration on the movement.	1
B	
Very responsive to the controls, but lag made it easy to overcompensate.	1
Difficult to steer while moving forward, otherwise it was good.	1
Hard to adjust drifting without overcompensating.	1
Turning right tends to pull backward.	1
Steering functions were impaired due to the sensitivity of the analog sticks.	1
Speed control was an issue for me. The controller is very sensitive.	3
Seemed like it moved like a button instead of a positional switch.	1
To control the robot with this specific controller was more difficult and took more time to maneuver.	1
Moving tasks are much more difficult than stationary. With practice, task can become easier to perform.	1

Comments	**No. of Responses**
One control stick should control the forward movement the other should control left and right movement. Also, movement should be controlled by right hand.	1

C

Relatively easy to work with limited exposure to device.	1
Much easier to use for me.	1
Driving and turning at the same time was very easy.	1
Sensitivity of thumb stick was good because it helped get rid of over correction.	1
Not being able to do multiple tasks at the same time.	3
Not being able to perform multiple tasks, as with zoom in or out while tracking made it difficult to pinpoint what an object is. More concentration was needed to switch to the modes making the task at hand more time consuming.	1
Nearly impossible to perform tasks simultaneously, but it would not take long to learn to perform functions quickly.	1
Having to toggle between different stations is really frustrating.	2
The need to switch modes made me unable to zoom out while tracking my target.	1
I think the flippers and sensor head should switch positions on the controller.	1
One or two more hours using the controller would've made a difference.	1
The camera toggle sticks or jumps.	1

6. During this trial, did you experience any of the following?

	Number of Responses		
	A	**B**	**C**
Wrist strain	0	0	1
Arm strain	0	0	4
Hand strain	0	0	5
Finger Strain	0	0	4
Nausea	0	0	0
Fatigue	0	0	0
Disorientation	0	1	0
Dizziness	0	0	0
Other?	0	0	0

C

Fingers slipping.	1
Got tired from arm and hand strain.	1
Wrist strain; soreness/CT.	1
Arm strain holding the weapon.	1
Arm got tired.	1
Hand strain having to use fingertips.	2
Finger strain using toggle with thumb.	2
Could be physically straining if had to perform for long periods of time.	1

7. Using the scale below, please rate the following characteristics of the controller that you just used:

1	2	3	4	5	6	7
Extremely bad	Very bad	Bad	Neutral	Good	Very good	Extremely good

CONTROLLER CHARACTERISTICS	MEAN RESPONSE		
	A	B	C
Size of controller	4.00	6.33	5.00
Size of individual controls	4.93	6.33	5.07
Location of individual controls	5.67	6.07	4.67
Comfort while holding the controller	4.64	6.40	4.53
Weight of controller	4.07	6.40	4.80
Shape of controller	4.33	6.27	4.87
Mapping of controller functions	5.60	5.87	3.67

8. Using the scale below, what is your **overall rating** of the controller that you used this iteration?

1	2	3	4	5	6	7
Extremely bad	Very bad	Bad	Neutral	Good	Very good	Extremely good

MEAN RESPONSE		
A	B	C
5.36	5.67	4.50

Comments	**No. of Responses**
A	
Positive.	1
Good controller.	1
Easy to use and learn.	2
User friendly.	1
Controllability is good.	1
Very good control over speed of vehicle.	1
Operates very smooth.	1
Very well labeled and layout was ideal.	1
Good sensitivity on camera adjustments.	1
A large controller offers more functions and ease of use. In a situation where size didn't matter, this would be a great controller.	1
If I had to use as hand-held, instead of placing on a table, I'm sure it would be extremely difficult to maneuver.	1
Negatives outweighs the positives.	1
Make it more ergonomic to allow for ease of operation while holding.	1
Should weigh more.	1

Comments	No. of Responses
A bit large.	1
Needs to be a little more sensitive with the driving controls.	1
B	
The size, feel, and location of buttons is awesome.	1
Easy to learn.	1
Very light; fits comfortably in my hand.	1
Shape, weight, familiarity of design was good.	1
Control buttons ideally placed.	1
I like it; very ergonomic.	1
I liked it as it was very responsive.	1
It would help if the controller could be configured to the operator, i.e., right-handed person drives with right toggle.	1
Takes getting used to for the time lag.	1
Not best for tactical environment, but otherwise outstanding.	1
Complicated.	1
The mapping of the button functions needs work.	1
C	
Very easy to use.	1
I can't think of a better place on an M4 or in a combat environment to have this controller than where it is now.	1
The thumb stick should have a depression in it for your thumb.	1
Controller needs a textured thumb controller to avoid slipping in a very hot environment.	1
Less sensitive than B and allows for more precise movements that are easily controlled.	1
Cycling through a main menu can be complicated.	1
Requires too much time overall.	1
Would like to see multiple task options.	1
Just too hard to multitask. You need to be able to easily transition between modes. Maybe eliminate some.	1
Difficult and frustrating to keep switching between functions to make it perform.	1
Don't like one-hand control.	1

END OF EXPERIMENT

SAMPLE SIZE = 15

1. Using the scale below, please rank order the controllers in the order of your preference on the following characteristics by placing a "1" next to your favorite, a "2" next to your second choice, etc.

1	2	3
First choice	Second choice	Last choice

CHARACTERISTICS	MEAN RESPONSE		
	A	B	C
a. Comfort in the hand	2.33	1.33	2.33
b. Ease of use	1.60	1.73	2.67
c. Quickest to use	1.53	1.67	2.80
d. Ease of carrying with you on a mission	2.80	1.73	1.47
e. Best to take with you in battle	2.47	1.73	1.80

Comments	**No. of Responses**
Comfort in the hand	
A	
Most rugged.	1
Better controllability.	2
Still solid with both hands working.	1
A familiar shape, but awkward.	1
Too large; bulky.	3
If smaller, it would be better.	1
Very difficult to hold.	1
B	
Fit well in my hands.	2
Hand-held controller.	1
Very comfortable.	1
Lightest.	1
Had better ergonomics and access to buttons.	2
Very natural.	1
Most practical. Easily used while holding.	1
Easier to function.	1
Mapped ideally and clearly labeled.	1
Allows multi-functions using thumbs and fingers.	1
It feels like a game controller.	1
Too sensitive.	2
Hard to control speed.	1

Comments	No. of Responses
C	
It fits in palm of one hand.	2
Easier for me to control rate of speed and azimuth simultaneously.	1
Ergonomic and easy to use.	1
Awkward, but convenient.	1
Very tricky to change commands.	1
Very difficult.	1
Too complex for simple tasks.	1
Limited to one hand which can experience fatigue.	1
Cumbersome.	1
Too much with the weapon.	1
Ease of use	
A	
Very basic and large, making it easy to use.	5
Simple.	2
Controls are very practical.	1
Less sensitive so lag wasn't difficult to adjust.	1
Targeting is rather easy on all.	1
Less buttons and all were labeled.	2
Not as well mapped/labeled as B.	1
Too bulky.	2
Joysticks multi-functioning a poor idea.	1
Almost everything is done with two controls on this one.	1
B	
Game controller.	1
Easy to use.	3
Clearly marked; no confusion; natural.	1
Every button could be reached easily. Your hands never had to leave the controller.	1
Light and ready to use with functions at fingertips.	1
Small, but more buttons.	1
Little to no switching between modes.	1
A close second.	1
Targeting is rather easy on all.	1
Very difficult to use.	1
C	
Easier for me to control rate of speed and azimuth simultaneously.	1
Targeting is rather easy on all.	1
4 buttons.	1
Didn't function right.	1
Very difficult to use.	1
Display system much more complicated than others; time consuming.	1
Not as fluid.	1

Comments	No. of Responses
Difficult to find the control you need.	1
A lot of hit and miss to change modes.	1
Takes a few minutes to get used to.	1
Quickest to use	
A	
Every use written on keypad/controller.	2
Big, labeled buttons.	2
Very natural.	1
No multi-tasking.	1
I could have easily figured out the controls without any guidance.	1
All controls could be reached from one position, never requiring much movement.	1
B	
More single function buttons.	2
Closest to the controllers I'm used to, so it was the easiest to just pick up and use.	1
Most familiar to me.	1
Most sensitive.	1
Limited multi-tasking.	1
Too many buttons for functions.	1
Required some movement.	1
Set up much like a gaming controller.	1
C	
All multi-function buttons.	
Modes are a work around for limited inputs, but having more inputs is essential for multi-function.	1
Controllers were easy to use. I could toggle through and select tasks.	1
Very difficult to switch modes.	1
Had too much mode switching.	1
Slow because you have to cycle thru everything.	1
Required almost constant movement to change modes.	1
Nothing is labeled and takes a little getting used too.	1
Ease of carrying with you on a mission	
This is a size issue.	1
A	
Fit as a natural piece of the weapon.	1
Smallest/lightest.	1
Too big, bulky.	3
B	
Lightest.	4
Easy and small.	5
Small, but still is extra component.	1
C	
Just attaches to your weapon and you don't have to think about it.	4

Comments	No. of Responses
Device C if it was not attached to the weapon.	1
Would be right on the rifle.	1
Very practical since it may attach to the RAS.	1
Too large.	2
Obvious here.	1
Size of controller matters for packing in ruck.	1
Will work on an M-4, but at what cost to the warrior?	1
Best to take with you in battle	
This is a size issue.	1
A	
Fit as a natural piece of the weapon.	1
Smallest, lightest.	1
Easy to use.	1
Actually works.	1
Too big, bulky.	2
B	
Second best since it is so small.	3
Durable.	1
Light.	2
Easiest to use without looking once functions are learned.	1
Small, but still is extra component.	2
C	
Best since it is on your weapon.	1
Already on weapon and ready to use.	1
Attaches to the weapon and you can maintain a hand on the grip of the weapon. But since you are so involved in the operation of the robot, you won't be able to effectively use your weapon.	1
Convenient, but in a bad place for battery to break off or get damaged.	1
Too large.	2
Looks like PAQ-4C and front M-4 handle.	1
Will work on an M-4, but at what cost to the warrior?	1
Compacting equipment is always practical.	1
This would not be something a rifleman should have.	1

2. Please provide suggestions for improvement in the following areas:

a. Suggestions for ways to increase the effectiveness of the controllers.

A	
Smaller design.	3
Easier to handle.	1
Use the buttons for multi-function tasks.	1

Comments	No. of Responses
Lets users map their own controls.	1
No malfunction with joysticks.	1
Be able to select the sensitivity of the thumb sticks!!!	1
If it is a two-handed controller, make it where it can be tailored to the person, i.e., left or right-handed.	1
Decrease lag.	1
Hand-held separate controller.	1
Less sensitivity of controllers.	2
Zoom control on the twist axis of the controllers.	1
B	
Attach to weapon somehow.	1
Have both thumb sticks on the control movement.	1
Make the two-handed controller where you can adjust the sensitivity.	1
Make just a hair more rugged.	1
Make more user friendly.	1
Use face buttons for 3 separate cameras and last for select.	1
Less switching between modes the better.	1
Reduce sensitivity of steering.	1
Minimize camera delay.	1
Remove superfluous buttons.	1
Wireless.	1
C	
Small joystick on it.	1
Easier.	1
Faster to use.	1
When zoomed in, sensitivity goes down so you don't over shoot.	1
Make the one-handed controller able to be multi-functioning.	1
Make less sensitive to overcome lag.	1
Input into a HUD.	1
Create a function to rotate 180 degrees.	1
Smaller.	1
A textured grip.	1
Able to adjust rate of acceleration.	1
Not really a good idea.	1
Move brake to another place (or make it automatic).	1
Use bottom button for drive mode default (a home button).	1
Remap buttons; awkward to select with pinky and ring finger..	1
Add buttons; using display navigation is slow.	1
Tighten the toggle for less exaggerating of maneuvers.	1

Comments	**No. of Responses**
b. Suggestions on ways to improve the training course.	
Course was great.	3
Did a great job of simulating the needs of the equipment.	1
Shorter day.	1
Multi-testing by all testers.	1
More tasks that require multi-tasking.	1
More tracking of targets.	1
Track a moving target over uneven terrain.	1
Track a target while moving.	1
Going under obstacles, like cars.	1
Raise the engineer tape to six inches.	1
Controls and different maneuvers.	1
Make course harder.	1
More obstacles.	2
Add IED or other training robot.	1
Reduce training time to 30, then 25, then, 20.	1
Vary course a little. Can be repetitive. Go thru the other way.	1
Multiple robots at once.	1
Use tactical situations.	1
Increase difficulty.	1
c. Suggestions on ways to improve the driving lanes that you negotiated	
No need to change; accomplished.	1
Desired mission.	1
Rooms (urban terrain).	1
Make one longer to see how people adjust for slight drifting in forward movement.	1
Make driving lane more defined.	1
Make lanes rougher to negotiate.	3
Maneuver more turns.	1
Drive with lights on (dark).	1
More terrain obstacles (i.e., wet ground, mud, rubble).	3
Longer straight-aways.	1
Make some with overhead cover.	1

d. Which would you prefer?

__4__ One-handed control operation
__11__ Two-handed control operation

Comments	No. of Responses
One-handed	
Allows free use of other hand for tactical environments, et.	2
Easier.	1
Needs to be multi-taskable.	1
Two-handed	
Allows for more ease of control and makes for an overall less complicated system.	1
Keeping maneuvers to the left and specific tasks on the right worked well.	1
To change modes.	1
Means I can do more at one time.	1
Feels more stable.	1
Requires less mode changes which can complicate/slow down process.	1
Opens up more options for functions.	1

e. Did you have any difficulty operating the controls on the Q3D with your left hand?

4 Yes
11 No

No. In fact, I used my left hand, but only because I felt like I had to have my firing hand on my weapon.	1
Didn't require dominant-arm-strength/coordination. Controls were simple enough to use a non-dominant hand.	1
	1
I'm used to firing my weapon left-handed so it made it easier.	3
Just changing menus was challenging.	1
Too much switching between modes.	1
I would have to have a lot of practice with this device.	1
Got fatigued quickly.	1
Very uncomfortable.	1

3. Using the scale below, please rank the following features in terms of importance in a robotic hand controller by placing a "1" next to your favorite, a "2" next to your second choice, etc.

1	**2**	**3**	**4**	**5**	**6**
First choice	Second choice	Third choice	Fourth choice	Fifth choice	Last choice

	MEAN RESPONSE
Comfort in hand	2.79
Size	3.07
Weight	4.21
Ruggedness	4.57
Maintenance free	3.57
Intuitiveness of controls	2.60

4. Please answer the following questions on the entire controller system (processor, antennae, cables, etc.)

a. Would you want to carry/wear the controller system?

__10__ Yes
___4__ No
___1__ Don't know

Comments	**No. of Responses**
No, Solders carry enough already.	2
It's a laptop and controller. It would weigh less than the radios.	1
Why would we wear it? Keep it in a case with the robot.	1
Did not experience the weight of the robot itself. If light enough, this piece of equipment will serve a great purpose to any Solder.	1
Too fragile for combat.	1

b. Please provide as many adjectives as you can think of describing only the hardware of the controller system (processor, antennae, cables, display, hand controller, etc.)

Expensive.	1
Durable.	1
Easy.	2
Basic.	1
Small.	2
Compact.	1
Lightweight.	1
Efficient.	1
Laggy.	1
Rugged.	2
Rough.	1
Cool.	1
Agile.	1
Versatile.	1
Impressive picture.	1
Programming bugs.	1
Heavy.	1
Need to be condensed.	1
Too many wires hanging out.	1
Not too rugged looking.	1
A bit much with a full combat load with body armor.	1
Simple, yet unreliable.	2

c. If you could name the robot you've been controlling, what would you name it?

Threat Negator.	1
Stalker.	1
Bob.	1
Johnny 5.	4
Besides Johnny 5? How about Chuck. I've never known a Chuck, but this robot sure acts like one.	1
Roger.	1

Comments	No. of Responses
Urban surveillance electronic robot (USER).	1
Recon ranger.	1
The Mole.	1
Breland-Bot.	1
Red Max; Red Hot.	1

6. Using the scale below, please rate the importance of the following driving tasks that are needed for teleoperating a robot.

1	**2**	**3**	**4**	**5**	**6**	**7**
Extremely Unimportant	Very Unimportant	Unimportant	Neutral	Important	Very Important	Extremely Important

DRIVING TASKS	MEAN RESPONSE
a. Heading information	5.20
b. Relative distance to obstacles	5.93
c. Depth of pot holes	5.67
d. Information on the navigability of down slopes (tilt meter)	5.53
e. Information on the navigability of side slopes (tilt meter)	5.40
f. Identification of other terrain features that might have an adverse effect on the ability of the robot to maneuver through the terrain (describe)	5.43
g. Ability to determine where the sides of the vehicle are located. (sides are in the camera field of view or are marked on the screen)	5.60
h. Ability to determine where the front of the vehicle is located	5.73
i. Ability to determine where the back of the vehicle is located	4.93
j. Information concerning whether the ground clearance of the vehicle will k. allow negotiation of rugged terrain	5.27
l. Indication of the turn radius of the vehicle	5.00
m. Information on the terrain closer than 6 inches in front of the vehicle	5.57
n. Information on the terrain five to 15 feet in front of the vehicle	5.13
o. Information on the terrain greater than 15 feet in front of the vehicle	4.67
p. Information on the current speed of the vehicle (speedometer)	4.20
q. Information on vehicle RPMs	3.27
r. Information on the way the vehicle motor sounds	4.40
s. Information on the other noises present in the vehicle's environment	5.13
t. Information concerning the color of objects in the environment (color vs. black and white camera)	5.20
u. Information concerning objects on the side of the vehicle (side facing cameras)	5.00
v. Information concerning objects behind the vehicle (back facing camera)	5.13
w. Information concerning the condition of the vehicle tires/tracks.	5.00

(continued on next page)

(cont)

DRIVING TASKS	MEAN RESPONSE
x. Information concerning the temperature of the vehicle	4.60
y. Feedback on the ruggedness of terrain.	4.67
z. Information concerning any delay between the time the operator sends a vehicle command and the time that the vehicle responds (i.e., how long after a stop command is sent before the vehicle actually stops)	5.73
aa. Feedback concerning whether or not the vehicle correctly received a command	4.87
bb. Battery status	6.20
cc. Fuel status	6.07
dd. Vehicle temperature	5.27

Comments	No. of Responses
f. sand/muck, rocket, clearance under objects.	1
Most important is lag time info.	1
I think 360 degree awareness around the robot is important because someone could easily sneak up on or sneak by otherwise. Also, many threats could go undetected without 360 degree awareness.	1
You should know how loud the robot is being if it must be stealthy.	1
Color is important because it can go to identification.	1
The lag could pose challenges until it is the user adjusts to it. The B controller would be the best option regarding size and mapping of controls.	1
A HUD.	1

7. The purpose of this experiment was to determine the feasibility of reducing the size of the robotic controller for use by dismounted Solders. Based upon what you've seen, is it feasible to reduce the size of the controller without adversely impacting performance by:

a. Shrinking the controller by shrinking it's controls sizes?

_10_ Yes
_5_ No

Shrink Device A.	1
Device B was easiest to use and had the smallest learning curve.	1
Device C is a very good size.	1
Device C is perfect for combat.	1
Shrinking controls seems relatively uncomplicated.	1
Not worth shrinking anymore; all three are fairly small.	1
The smaller, the more comfortable it was to use.	1
Smaller controls don't impact the performance.	1
The sizes are correct for the size of the individual controls.	1
If having to carry it, it would be useful if smaller.	1

b. Shrinking the size of the controller by reducing the number of controls?

__5__ Yes
_10_ No

Comments	**No. of Responses**
For the first two.	1
Will increase time spent performing control tasks.	1
It is easier to control the robot and can more timely do so with more buttons.	1
If done right, this could work, but this prototype wasn't user friendly.	1
Make more user friendly.	1
To reduce much would adversely affect performance.	1
Having to switch between modes to complete a maneuver wasted time.	1
More controls are needed to make it faster and easier.	1
Device C swapped user friendliness for less controls – bad!	1
Having the press the same button over and over was annoying.	1

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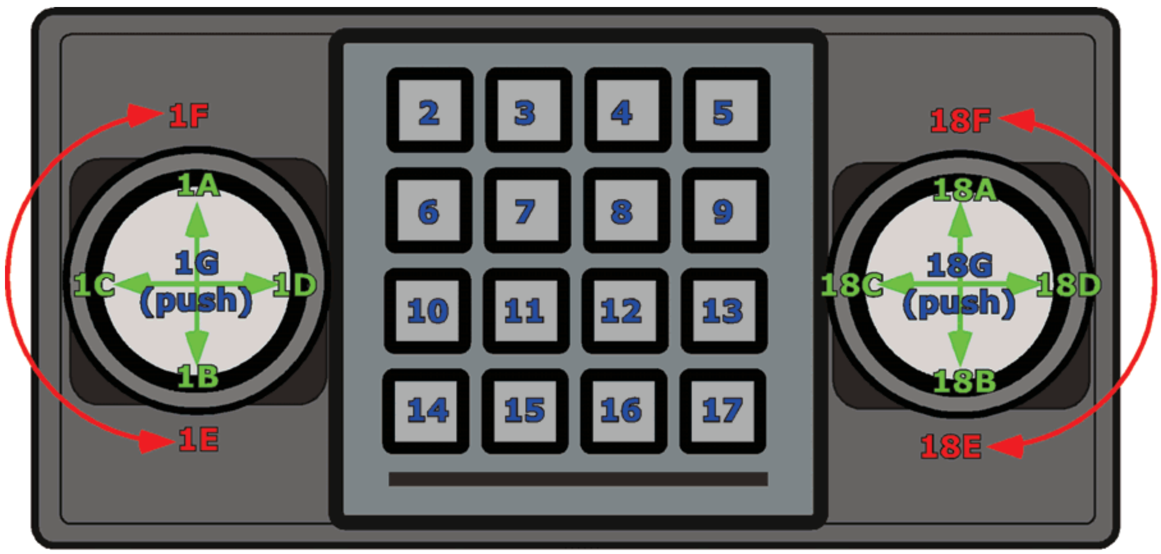
Appendix B. Control Intuitiveness Test Results

Controller A



Controller A					
1. Raise the arm of the sensor head.					
Control	**First Choice**	**Second Choice**	**Third Choice**	**Total**	**Weighted Totals**
1A	2	2	1	5	11
1B	1	0	1	2	4
1C	0	0	1	1	1
1E	0	0	1	1	1
2	3	2	0	5	13
3	0	0	1	1	1
5	1	1	4	6	9
6	0	2	0	2	4
11	0	0	1	1	1
14	1	0	1	2	4
18A	3	2	0	5	13
18B	1	2	0	3	7
18E*	0	1	0	1	2*
18F	0	0	1	1	1
2. Raise the flippers.					
Control	**First Choice**	**Second Choice**	**Third Choice**	**Total**	**Weighted Totals**
1A	2	1	0	3	8
1B	0	0	1	1	1
1C	0	1	0	1	2

(cont)

2. Raise the flippers.					
Control	**First Choice**	**Second Choice**	**Third Choice**	**Total**	**Weighted Totals**
1E	1	0	0	1	3
1F*	1	0	0	1	3*
2	3	0	2	5	11
4	0	0	1	1	1
5	0	2	1	3	5
10	0	0	1	1	1
11	1	0	0	1	3
12	0	0	1	1	1
13	0	1	0	1	2
14	0	2	1	3	5
17	2	1	2	5	10
18A	0	2	0	2	4
18B	0	1	1	2	3
18F	2	0	0	2	8
3. Drive the robot forward.					
Control	**First Choice**	**Second Choice**	**Third Choice**	**Total**	**Weighted Totals**
1A*	9	5	0	14	37*
1B	0	1	0	1	2
18A	3	0	1	4	10
4. Brake.					
Control	**First Choice**	**Second Choice**	**Third Choice**	**Total**	**Weighted Totals**
1B	2	1	0	3	7
1C	0	0	1	1	1
1E	0	0	1	1	1
1G	1	0	0	1	3
2	0	1	0	1	2
3	0	0	1	1	1
4	0	0	1	1	1
5	1	0	0	1	3
14*	2	2	2	6	12*
15	2	1	0	3	8
16	0	2	1	3	5
17	3	0	1	2	10
18B	1	2	1	4	8
18G	0	1	0	1	2
5. Pan the camera left.					
Control	**First Choice**	**Second Choice**	**Third Choice**	**Total**	**Weighted Totals**
1C	2	2	1	5	11
1E	3	0	0	3	9

(cont)

5. Pan the camera left.					
Control	**First Choice**	**Second Choice**	**Third Choice**	**Total**	**Weighted Totals**
6	0	1	1	2	3
10	1	1	0	2	5
11	0	0	1	1	1
14	1	0	0	1	3
18C*	4	2	1	7	17*
18E	1	2	1	4	8

*Correct choice based on current mapping.

Controller A

1. Raise the Arm

First Choice Response	Reason selected	No. Responses
1A	Direction; on left	1
	Guess	1
1B	Intuitive; flight analogy	1
2	Important function; should have easy access	1
	Intuitive	1
5	Guess	1
14	Button is easy to reach and prefer to use joystick	1
18A	Assume left toggle for driving; camera second most important	1
	Main function, so should be main control	1
	Video game analogy	1
18B	Seems most logical; left stick for driving, right for camera	1

Second Choice Response		
1A	Directional motion	1
	Easy to operate	1

		No. of Responses
2	Each row could represent a different part of the robot	1
	Guess	1
5	Guess	1
6	Process of elimination	1
	Would want close to left hand	1
18A	Guess	1
	Joystick seems probable	1
18B	Guess	1
	Second most logical	1
18E	Process of elimination; joysticks appear for track so must be button	1
Third Choice Response		
1A	Most sensitive control	1
1B	Joystick natural for controlling direction	1
1C	Left or right motion makes sense for moving head	1
1E	Guess	1
3	Top of the key pad equals up	1
5	Closest button if driving with right hand	1
	Easy access	1
	Guess	1
11	Could be arrow pad	1
14	Guess	1
18F	Simple movement	1

2. Raise the Flipper

First Choice Response		
1A	Move quickly	1
	Up and down motion	1

		No. of Responses
1E	Two directional analog	1
1F	Turn for up or down	1
2	Each row for different part of robot	1
	Guess	1
	Top of control	1
11	Buttons may be arrow pad	1
17	Easy to reach	1
	Flippers located opposite of neck on robot so opposite on keyboard	1
18F	Guess	1
	Joystick for movement	1
Second Choice Response		
1A	Assigns direction	1
1C	Same as 1; hands already on stick for driving	1
5	Guess	1
13	Process of elimination	1
14	Easy to reach with non driving hand	1
17	Guess	1
18B	Direction easy to control	1
Third Choice Response		
1B	Guess	1
2	Guess	2
4	Process of elimination	1

		No. of Responses
5	Assume would be upper button	1
10	Same; process of elimination	1
12	Process of elimination	1
14	Easy to reach with thumb	1
17	Easy to reach with driving hand Guess	1
18B	Could use it while driving	1

3. Drive the robot forward.

First Choice Response		
1A	Directional	1
	Feels natural	1
	Makes sense; easy to use	2
	Left hand dominant	1
	Most sensitive to direction; assume left	1
	Usually left controls body	1
	Guess	1
	Two track should have two movements	1
18A	Drive with right hand	1
	Steering easier with right hand	2

Second Choice Response		
1A	Guess	2
	Next best choice	1
	Process of elimination	1
	Second most logical	1
1B	Same as 1 but opposite direction	1

Third Choice Response		
18A	If not. two controls would drive with right hand	1

4. Brake.

First Choice Response		No. of Responses
1B	Could easily stop	1
	Opposite of driving forward	1
1G	Brake analogy	1
5	Won't use often so furthest away	1
14	Easy to reach quickly	1
	Makes sense	1
15	Guess	2
17	Brake should be near drive control	1
	If driving with right hand easiest to reach	1
	Intuitive to use thumb for brake	1
18B	Opposite of driving forward	1

Second Choice Response		
1B	Opposite direction of motion	1
2	Same as first	1
14	Easiest to reach with other hand	1
	Same as 1	1
15	Close to drive; lower end of keypad	1
16	Guess	2
18B	Same as 1	2
18G	Same as 1	1

Third Choice Response

		No. of Responses
1C	Wouldn't want to push button	1
1E	Twisting motion like pan motion	1
3	Guess	1
4	Guess	1
14	Easily reachable from drive control	1
	Same as 1	1
16	Process of elimination	1
17	Peripheral	1
18B	Pull back to stop	1

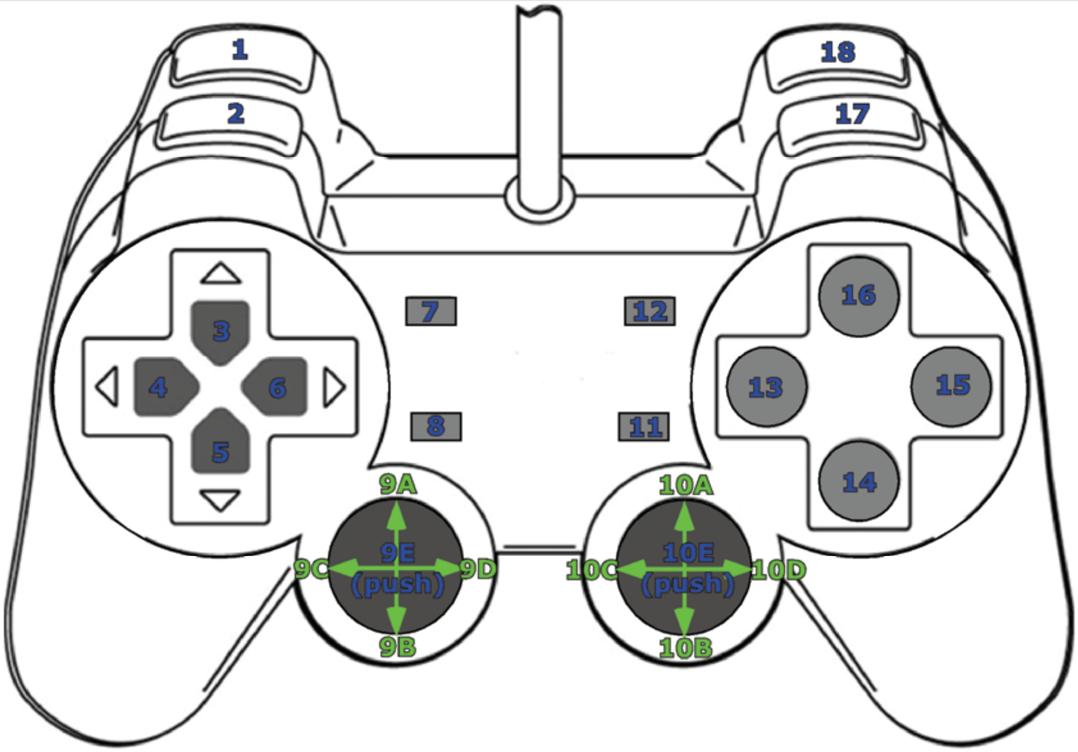
5. Pan the camera left.

First Choice Response

1C	If driving with right hand would want camera on the left	1
	Left side	1
1E	Guess	1
	Knob has left and right direction	1
	Turn left with left hand	1
10	Hadn't used row yet	1
14	Left side of keyboard; lower priority function	1
18C	Guess	1
	If related to moving the neck should also move the camera	1
	Intuitive	1
	Sensitive control	1
18E	Same as 1	1

Second Choice Response		No. of Responses
1C	First person shooter game analogy	1
	Left side	1
6	Second most intuitive	1
10	Process of elimination	1
18C	Feels most natural	1
	Next best choice	1
18E	Guess	1
	Same as 1	1
Third Choice Response		
1C	Guess	1
6	Guess	1
11	Process of elimination	1
18C	Easier	1
18E	If not for driving makes sense for camera control	1

Controller B



Controller B					
1. Raise the arm of the sensor head.					
Control	**First Choice**	**Second Choice**	**Third Choice**	**Total**	**Weighted Totals**
1	0	1	0	1	2
2*	2	2	2	6	12*
3	3	1	3	7	14
5	0	1	0	1	2
9A	1	1	1	3	6
9B	1	0	1	2	4
10A	4	2	0	6	16
10B	1	0	1	2	4
16	0	2	2	4	6
17	2	1	1	4	9
18	1	1	0	2	5

2. Raise the flippers.

Control	First Choice	Second Choice	Third Choice	Total	Weighted Totals
1	2	0	0	2	6
2	3	0	1	4	10
3	1	2	1	4	8
7	0	0	1	1	1
9A	1	1	1	3	6
9D	0	0	1	1	1
10A	1	2	0	3	7
12	0	1	1	2	3
16	2	1	1	4	9
17*	5	3	1	9	22*
18	0	1	0	1	2

3. Drive the robot forward.

Control	First Choice	Second Choice	Third Choice	Total	Weighted Totals
2	0	0	1	1	1
3	4	2	1	7	17
9A*	8	5	2	15	36*
9B	0	1	0	1	2
10A	2	1	1	4	9
16	0	1	0	1	2

4. Brake.

Control	First Choice	Second Choice	Third Choice	Total	Weighted Totals
1	0	1	0	1	2
1B	1	0	0	1	3
2	1	0	1	2	4
5	1	0	0	1	3
7*	1	0	2	3	5*
8	0	2	1	3	5
9B	1	1	0	2	5
9E	0	0	1	1	1
10E	1	1	0	2	5
11	3	0	0	3	9
12	0	1	1	2	3
13	2	1	1	4	9
14	3	3	3	9	18
15	1	1	0	2	5
17	0	2	1	3	5
18	0	1	3	4	5

5. Pan the camera to the left.					
Control	**First Choice**	**Second Choice**	**Third Choice**	**Total**	**Weighted Totals**
1	1	0	0	1	3
2	0	1	3	4	5
3	0	1	0	1	2
4	4	2	2	8	18
9C	4	3	1	8	19
10C*	4	3	3	10	21*
10D	1	0	0	1	3

*Current correct choice.

Controller B

1. Raise the Arm

First Choice Response	Reason selected	No. Responses
2	Guess	1
	Makes sense	1
3	Axis of movement appears similar to robot	1
	Guess	1
	Other direction controls assumed to be for other tasks	1
9A	Directional control	1
9B	Prefer to drive with right and use left for peripheral	1
10A	Assume left toggle for driving; camera second most important	1
	Easy to reach and move	1
	Pivot control; right handed	1
	Right handed	1
10B	Seemed related to arm motion	1
17	Digital analog of up and down	1
	Makes sense	1
18	Easy to reach	1

Second Choice Response		No. of Responses
1	Same as 1	1
2	Can press quickly	1
	Same as 1	1
3	Arrow up makes sense to move up; video game analogy	1
5	Next closest to left hand; pull up analogy	1
9A	Direction	1
	Same sort of control as first choice	1
10A	More comfortable; directional	1
	Try different direction	1
16	13-16 directional mapping	1
	Right side preference	1
17	Right handed	1
18	Opposite orientation of first choice	1

Third Choice Response		No. of Responses
2	Feels like up	1
	Same as 1	1
3	Arrow signifies up	1
	Direction arrow	2
9A	Same as 2	1
9B	Seems to be toggle	1
10B	Only logical choice left	1
16	Four button could represent axis of movement	1
	Top equals up	1
17	Same as 1	1

2. Raise the Flipper

First Choice Response

		No. of Responses
1	Head top feet bottom	1
	Convenient for up and down	1
2	Looks like physical layout of the robot	1
	Seems logical for up	1
	Flippers independent	1
9A	One control for each flipper	1
10A	Right handed	1
16	Neck control and flipper control should be parallel	1
	Up direction	1
17	Guess	2
	Lower priority task; out of the way; don't need high sensitivity	1
	Makes sense	1
	Seem to relate to up and down	1

Second Choice Response

3	Direction	1
	Same as 1	1
9A	Direction makes sense	1
10A	Drive with right hand	1
	Process of elimination	1
12	Guess	1
16	Up direction	1
17	If left buttons for neck then right for flippers	1
	Same as 1	2
18	Same as 1	1

Third Choice Response		**No. of Responses**
2	Top and bottom correspond to up and down; one set for each flipper	1
3	Up arrow	1
7	Guess	1
9A	Next logical choice	1
9D	Two flippers should have two controls	1
	Looks like it would be up and the one below it down	1
	Makes sense	1
	Top button; quick raise	1

3. Drive the robot forward.

First Choice Response		
3	Direction arrow	1
	Direction pad typical for forward movement; video game analogy	1
	Forward arrow	1
	Video game analogy	1
9A	Easier to maneuver	1
	Easy to use with thumb; main function	1
	Easy to use; video game function	1
	Has swivel for direction; more freedom of movement	1
	Most sensitive to direction	1
	Control speed and direction	1
	Direction; on for each track	1
	Tank analogy	1
10A	Drive with right hand	1
	Driving most important task; right handed; sensitive to pressure, gas pressure analogy	1
	Right handed; analog stick	1

Second Choice Response		**No. of Responses**
3	Forward arrow	1
	Only other logical choice	1
9A	Next logical choice	1
	Process of elimination; left hand dominant	1
	Same as 1	1
	Video game analogy	1
	One control for each track	1
9B	Same as 1 but opposite direction	1
10A	Right handed; seems logical	1
16	Right handed	1

Third Choice Response		
2	Process of elimination	1
3	Directional pad	1
9A	Easy to use analog stick	1
	Process of elimination	1
10A	Guess	1

4. Brake.

First Choice Response		
1B	Can slow while driving	1
2	Close to forward button	1
5	Pull back brake analogy	1
7	Process of elimination	1
9B	Opposite of drive forward	1

		No. of Responses
10E	Driving control; brake analogy	1
11	Closest to driving control	1
	Low priority function; don't want to accidentally press; video game pause button	1
	Process of elimination	1
13	Analogy to video game	1
	Video game analogy	1
14	Closest to thumb; wouldn't be directional	1
	Should be a button type control; close to thumb is convenient	2
15	Should be a button type control	1
Second Choice Response		
1	Hands off all other buttons	1
8	Easy to reach; doesn't seem like priority	1
	Same as 1	1
9B	Backward motion to stop	1
10E	Intuitive	1
12	Easy to reach with thumb	1
13	Same as 1	1
14	Drive with left and brake with right	1
	Easy to reach with thumb	1
	Feels natural to press for brake	1
15	Next to first choice	1
17	Out of the way of other controls	1
	Same as 1; proximity to index finger makes in convenient	1
18	Guess	1

Third Choice Response		No. of Responses
2	Easy to press quickly	1
7	Not easily confused with other controls	1
	Same as 2	1
8	Guess	1
9E	Makes sense	1
12	Same as 1	1
13	Guess	1
14	Down position	1
	Process of elimination	1
	Seems unrelated to other functions so off to the side	1
17	Guess	1
18	Easy access	1
	Easy to reach with fingers	1
	Same as 1; process of elimination	1

5. Pan the camera left.

First Choice Response		
1	Guess	1
4	Directional pad	2
	Easy to change	1
	Makes sense	1
9C	Easy to move with toggle control	1
	Joystick should move camera left and right and the neck up and down	1
	Non dominant hand; high priority function; speed and direction	1
	Right to drive; left for camera; video game analogy	1

		No. of Responses
10C	Affordance to turn 360 degrees; right handed	1
	If left toggle is drive the right should be for the camera	1
	Logical choice; right control usually for head	1
	Sensitive control	1
	Point in direction of motion	1
13	Buttons 13-16 create up-down, left -right layout	1
Second Choice Response		
2	Left control; top button can be pressed quickly	1
3	Left arrow	1
4	Directional arrows	1
	Directional pad	1
9C	Left side and left direction	1
	Makes sense	1
	Next to first choice	1
10C	Directional; drive with left hand, control camera with right	1
	If not for driving would make sense	1
	Prefer to use left hand for view	1
13	Wouldn't use toggle	1
Third Choice Response		
2	Could use simultaneously with other functions	1
	Easy access; on left side	1
	Guess	1
4	Direction arrow	1
	Only directional control left	1
9C	Guess	1
10C	Process of elimination	1
	Same as 1	1
	Toggle direction	1

Controller C

Controller C					
1. Raise the arm of the sensor head.					
Control	**First Choice**	**Second Choice**	**Third Choice**	**Total**	**Weighted Totals**
1A	8	4	2	14	34
1B	0	2	0	2	4
1D*	0	0	1	1	2*
2	4	5	0	9	22
3	1	1	5	7	10
4	0	0	3	3	3
5	0	0	1	1	1
6A	0	1	0	1	2
2. Raise the flippers.					
Control	**First Choice**	**Second Choice**	**Third Choice**	**Total**	**Weighted Totals**
1A*	4	3	3	10	21*
2	3	3	0	6	15

(cont)

2. Raise the flippers.					
3	1	2	5	8	12
4	3	1	2	6	13
5	1	1	0	2	5
6A	1	0	0	1	3
6B	0	1	0	1	2

3. Drive the robot forward.

Control	First Choice	Second Choice	Third Choice	Total	Weighted Totals
1A*	13	0	0	13	39*

4. Brake.

Control	First Choice	Second Choice	Third Choice	Total	Weighted Totals
1B	1	0	1	2	4
1E	4	1	1	6	15
2	2	4	0	6	14
3	0	0	3	3	3
4	1	0	0	1	3
5*	4	3	0	7	18*
6A	0	0	1	1	1
6B	1	0	0	1	3
7	0	1	0	1	2

5. Pan the camera to the left.

Control	First Choice	Second Choice	Third Choice	Total	Weighted Totals
1C*	10	5	3	18	43*
2	0	1	0	1	2
4	1	0	0	1	3
5	0	0	1	1	1
6B	1	0	0	1	3

*Current correct choice.

Controller C

1. Raise the Arm

First Choice Response	Reason selected	No. Responses
1A	Convenient	1
	Directional pad; multipurpose	2
	If in correct mode obvious direction	1
	Only control with direction	1
	Makes sense	1

		No. of Responses
	Since only one direction control choose a button to specify mode	1
	Buttons for different modes	1
2	Easiest to reach	1
	Primary function; top equals up	2
	Starting from the top and work down	1
3	Meant to hit top button; up goes with top button	1
Second Choice Response		
1A	Directional motion	1
	Logical	1
	Place in mode	1
	Guess	1
1B	Convenient	1
	Only directional control	1
2	If not toggle, should be top button to equal up	1
	Main function so first button	1
	Top button means raise	1
	Toward top; more priority	1
	Up goes with higher located button	1
3	Process of elimination	1
6A	Standard position of neck is down so turn grip to the right to raise	1
Third Choice Response		
1A	Process of elimination	1
	Guess	1
1D	Right and left could mean up and down	1
3	Assume the first two buttons correspond to head	1
	Guess	2
	Next in line; primary function	1
	Process of elimination	1

		No. of Responses
4	Buttons are two pairs of up and down	1
	Process of elimination	2
5	Guess	1

2. Raise the Flipper

First Choice Response		
1A	Direction	1
	Directional control	1
	Logical	1
	Flippers lower priority	1
2	Lower relative to other buttons	1
	Secondary priority so not the toggle	1
	Top button equals up	1
3	Guess	1
4	Feels right	1
	Flippers lower priority	1
	Guess	1
5	Flippers lower priority	1
6A	Think toggle is for driving, so process of elimination	1

Second Choice Response		
1A	Direction	1
	Guess	2
2	Guess	1
	Convenient	1
	Top equals up	1
3	Guess	1
	Middle location on robot	1
4	Same as 1; process of elimination	1
5	Order of priority; process of elimination	1

		No. of Responses
6B	Same as 1	1

Third Choice Response

1A	If not for driving; directional control	1
	Guess	1
	Mode	1
3	Guess	4
	Same as 1	1
4	Guess	2

3. Drive the robot forward.

First Choice Response

1A	Directional control	5
	Driving most important task	1
	Feels natural	1
	Flexible to control movement	1
	Main function	1
	Most sensitive to direction	1
	Movement is natural for thumb; up equals forward	1
	Only one that makes sense	1
	Range of motion	1
3.2	None.	
3.3	None.	

4. Brake.

First Choice Response

1B	More control to move with thumb	1
1E	Brake analogy	1
	Easy if driving	1
	Guess	1
	Makes sense; standard in other controls	1
2	Guess	1
	Closest to driving control	1

		No. of Responses
4	Most convenient	1
5	Furthest away prevents confusion	1
	Least frequent use so furthest away	1
	Low priority; out of the way	1
	Out of the way	1
6B	Feels like halt, pull back	1
Second Choice Response		
1E	Brake in car analogy	1
2	Guess	1
	Close to drive	1
	Easy access	1
	Makes sense to press a button for brake	1
5	Guess	2
	Very end; low priority	1
7	If stop pressing controls should stop robot	1
Third Choice Response		
1B	Guess	1
1E	Guess	1
3	Guess	1
	Process of elimination	2
6A	Easy to reach	1
5. Pan the camera left.		
First Choice Response		
1C	Directional	4
	Left direction	1
	More flexible than buttons	1
	Toggle is for direction	1

		No. of Responses
	Guess	1
	Next main function	1
	Feels comfortable	1
4	Third button should be left and fourth right for camera	1
6B	Left handed	1
	Logical	1
Second Choice Response		
1C	Makes sense to use toggle to control view direction	1
	More access	1
	Easy	1
	Guess	2
2	Same logic as one for first and second button	1
Third Choice Response		
1C	Guess	2
	Next in line	1
5	Guess	1

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